MENTORED ENGAGEMENT OF SECONDARY SCIENCE STUDENTS, PLANT SCIENTISTS, AND TEACHERS IN AN INQUIRY-BASED ONLINE LEARNING ENVIRONMENT

A Dissertation

by

CHERYL ANN PETERSON

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2012

Major Subject: Curriculum and Instruction

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Approved by:

Chair of Committee,	Carol L. Stuessy
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	Cathleen Loving
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ABSTRACT

Mentored Engagement of Secondary Science Students, Plant Scientists, and Teachers in an Inquiry-Based Online Learning Environment. (August 2012)

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Chair of Advisory Committee: Dr. Carol L. Stuessy

PlantingScience (PS) is a unique web-based learning system designed to develop secondary students' scientific practices and proficiencies as they engage in hands-on classroom investigations while being mentored online by a scientist. Some students' teachers had the opportunity to attend PS professional development (PD). In this dissertation, I developed a process of assessing student learning outcomes associated with their use of this system and evaluated inquiry engagement within this system.

First, I developed a valid and reliable instrument (Online Elements of Inquiry Checklist; OEIC) to measure participants' (students, scientists, and teachers) engagement in scientific practices and proficiencies embedded within an inquiry cycle I collaborated with an expert-group to establish the OEIC's construct and content validities. An inter-rater reliability coefficient of 0.92 was established by scientists and a split half analysis was used to determine the instruments' internal consistency (Spearman-Brown coefficient of 0.96).

Next, I used the OEIC to evaluate inquiry cycle engagement by the participants who used the PS online platform designed by the Botanical Society of America which facilitated communication between participants. Students provided more evidence of engagement in the earlier phases of an inquiry cycle. Scientists showed a similar trend but emphasized experimental design and procedures. Teachers rarely engaged online. Exemplary students' outcomes followed similar inquiry cycle trends, but with more evidence of engagement with one notable difference. Exemplary students provided evidence for extensive engagement in immersion activities, implicating immersion as a crucial component of successful inquiry cycle engagement.

I also compared engagement outcomes of students whose teachers attended the PD experience to the students of teachers who did not attend PD. Differences found between the two groups occurred throughout the inquiry cycle, typically associated with experiences provided during the PD.

As a result of this research I have several recommendations about revisions to the PS online platform and use of approaches to assure students development of scientific practices and proficiencies. The recommendations include additional scaffolding of the platform, explicit inquiry cycle instruction, and continued opportunities for teachers to engage in PD experiences provided by PS.

DEDICATION

In memory of my grandmother, Mary Maxine Owens Erickson (1914-1998)

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I would like to extend my gratitude to the Botanical Society of America who generously allowed access to their *PlantingScience* online platform. I would also like to thank the *PlantingScience* students, teachers, and scientists and extend my gratitude to the National Science Foundation.

Thanks also go to my friends and colleagues and the department faculty and staff at Texas A&M University. In addition, I would like to thank the members of the BSA and PRISE research teams, especially Dane Bozeman, Ra'sheedah Richardson, and Dawoon Yoo, for their support over the past several years. I would also like to thank Dr. Schielack and the other members of the Information Technology in Science Center for supporting me during my early explorations into Science Education. In addition, I would also like to thank my university writing group.

Thanks are also extended to my family members, especially my parents and husband's parents, and to my friends, whom I also consider family. Finally, a very special thank you is extended to my husband, Shaun Torres, for his love, support, and seemingly endless patience.

NOMENCLATURE

BSA	Botanical Society of America
NSES	National Science Education Standards
PD	Professional Development
PS	*PlantingScience*
TSS	Taking Science to School

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE Page

LIST OF TABLES

TABLE Page

TABLE Page

CHAPTER I

INTRODUCTION

Learning and teaching are no longer bound by the walls of the classroom. Cyberlearning has brought about a revolution among curriculum designers that redistributes time, space, and materials to create anytime-anywhere learning environments (Pea, Borgman, Abelson, et al., 2008). Cyberlearning is used to create innovative learning systems that define new roles for learning materials, classroom learners, teachers, and assessment. Unfortunately, many teachers in the United States have not received the entire message. New technologies and learning environments mean new strategies for teaching, learning, and assessment. Most teachers and school districts are still bound by traditional learning systems valuing teacher-directed instruction, textbook-based curricula, outdated forms of summative assessments (Wood, 2009). Many teachers still have the notion that learning takes place in a brick and mortar building rather than in the minds of students.

When teachers begin to embrace technology, they have difficulties adopting these technologies in the classroom. A major problem continues to be assessment. While intuitively teachers know that new technologies imply new types of learning, ways to assess student learning in technology enhanced learning systems continues to be a mystery. Teachers embracing innovative learning systems face a steep learning curve.

This dissertation follows the style of *School Science and Mathematics*.

Researchers, assessing these new learning systems, should also study professional development (PD) programs that support teachers as they learn about and engage their potential to support teachers as they engage in new learning systems. In addition, students in these new learning systems (Peters & Slotta, 2010). PD programs have the reform-based PD can result in improved student outcomes (Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009).

PlantingScience (PS) is an award winning innovative learning system and was featured in Science magazine (Hemingway, Dahl, Haufler, & Stuessy, 2011). PS currently involves 3,000 student-teams, 150 classroom teachers in 34 different states, and over 900 volunteer scientist-mentors from 14 scientific societies. PS integrates innovative design, authentic science inquiry, and collaboration within an asynchronous learning network. The goal of PS is to "improve understanding of science while fostering an awareness of plants" (Hemingway, Dahl, Haufler, & Stuessy, 2011, p. 1535). Expert scientists are made accessible to secondary school classroom students through an online asynchronous communication-based platform. The platform facilitates scientific discourse and collaboration among secondary students, teachers, and scientist-mentors while incorporating authentic scientific inquiry into classroom instruction. The communication and collaboration can be observed online.

In addition to developing and hosting an innovating learning system, PS also provides quality PD. Support from the National Science foundation enabled the PS designer to offer PD training to science teachers as they interacted with the innovative learning system. About 60 teachers over 4 summers attended nine-day PD workshops.

During the first five days of the workshop teachers were led through modules by attending scientists involved in the initial design of the modules for classroom use. Workshop teachers were immersed in plant inquiries as learners, while the scientists provided them with an extensive plant content background and familiarized them with interactive tools available on the PS platform. Workshop teachers also shared "strategies for using online and classroom discourse and science notebooks as they designed an implementation plan for their own students" (Hemingway et al., 2011, p. 1536). Finally, workshop teachers became familiar with the online platform through direct instruction and use of the platform throughout the summer workshop.

Opportunities for traditional assessments of the PS innovative learning system were embedded within the PS online system. Pre- and post-tests were administered online by the teacher on the first day of the students' use of an inquiry module and after completion. Teachers selected questions from a list of questions that the PS facilitators developed for each module. The teachers selected the questions according to the learning objectives for their own classrooms. Thus they were able to created tests reflecting their unique classroom. Though students did show positive gains in their attitudes towards science, an analysis of these traditional assessments did not show any evidence of clear gains in the students' metacognitive or inquiry skills (Larson & Stuhlsatz, 2011). These results conflicted with the scientist-mentors' and teachers' positive perceptions of PS. The scientist-mentor and teacher reports indicated that they believed that students' engagement in the PS investigations aided students' education and understanding of science (Larson & Stuhlsatz, 2010).

The PS platform provides permanent access to all of the evidence of inquiry engagement that students post online. These records provide rich sources of data for assessment purposes. Data sources include students' online discourse with scientist-mentors, teachers, and other students and materials that the students upload to website. Materials include summaries, journals, graphs, data tables, pictures, audio/video files and final presentations.

Though these records of students' engagement in scientific practices and proficiencies are readily available and accessible, systematic methods of assessing these records are lacking. Records located on the PS online platform provide evidence for both formative and summative assessment purposes in a number of ways. The forum design can allow teachers and scientist-mentors access to students' ideas frequently with great ease. Since, teachers and scientist-mentors can see the variety and complexity of students' ideas; they can adapt their instruction to their students' needs. In addition they can unobtrusively and without interruption to the flow of students' progress conduct formative assessments of their students' progress. Summative assessments can occur after the students have uploaded their research information, journals, data, and final presentations.

The PS online platform provides a record of the students' projects making these projects easy to access long after the individual student teams' projects are complete. The various student products and collaborative discourse is available. Research into assessing this new learning system needs to occur. Traditional forms of assessment are insufficient in capturing the complexity of the quality and extent of engagement in the PS learning system.

Teachers are ill prepared to use and to assess student outcomes in these new and innovative learning systems. Extensive and content-rich professional development experiences, such as PS summer workshops, can provide that support that teachers need to implement and assess innovative learning systems in their own classrooms. PS, an online innovative learning system, provides a context in which ideas about authentic assessment can be designed, tested, and evaluated to develop methods for assessing student outcomes.

Purpose Statement

The overarching purpose of the research for this dissertation was to develop a process for assessing students' learning outcomes associated with their use of a unique learning environment, *PlantingScience*. *PlantingScience* is a unique web-based learning environment providing inquiry-based modules that emphasize students' use of scientific practices as they engage in hands-on classroom investigations investigation aspects of plant growth and development. An important aspect of the *PlantingScience* learning environment is an online mentorship component, which matches scientist-mentors with student-teams to provide assistance as student work through their *PlantingScience* inquiry modules. Another unique aspect of the learning environment is an online web-based platform supporting students' engagement in the module by providing opportunities for student to engage in discussions with others, including online scientist-mentors; and to post journal entries, scientific data, and summaries of their classroom investigations, To assess student learning outcomes, I developed an instrument to sue student-generated online data sources provide on the web to assess the quality of students' engagement in scientific practices a while they work through their scientific investigations.

Format of the Dissertation

In Chapter I, I present a brief introduction, a purpose statement, a set of research questions, and a series of potential implications. In Chapter II, I describe and synthesize the current educational literature related to innovative learning systems and scientific practices and proficiencies. In Chapters III, IV, and V, I present the results of three research studies. These chapters report the results of three separate yet related investigations, which I will submit for publication after the dissertation has been successfully defended. Chapter III details the development and validation of the instrument to assess participants (including students, scientists, and teachers) engagement in scientific practices and proficiencies during the course of plant-based scientific investigations for beginning to end. My use of the instrument is detailed in Chapter IV, which provides the results of an assessment of students' proficiencies in a random sample of students engaged in plant-based scientific investigations using the *PlantingScience* learning environment. In Chapter V, I again use the instrument to assess the value of summer professional development workshops for teachers who then engage their students in the *PlantingScience* learning environment. In this chapter, I use the instrument to compare the proficiencies in scientific practice of a set of workshop teachers' students with another set of students whose teacher did not attend a summer workshop. Finally, Chapter VI presents a synthesis of the findings and relates them to pattern theory.

Pattern Theory

This study allowed me to see patterns regarding the general state of assessment practices of the *PlantingScience* innovative online learning systems. However, assessment practices change over time. Pattern theory, a naturalistic form of model development, enables the researcher to reconcile the idea that a pattern is rarely if ever finished and that the pattern changes over time as new data becomes available. Approaching research from a pattern theory perspective also allows the researcher to explore the connections between the items under investigation without having to assign an order of importance amongst them (Lincoln & Guba, 1981). Pattern theory frees the researcher to explore the patterns of what is and flow with the changes that new data brings. I approached this dissertation and my studies' results with notions of pattern theory. I explored the connections between student outcomes and assessment with acceptance that delving deeper into my explorations of innovative online learning systems will reveal new patterns.

Research Questions

Chapter III in this dissertation is titled "Developing and Validating an Instrument to Measure Scientific Inquiry in an Online Mentored Learning Environment." The purpose of this mixed-methods study was to describe the development of an instrument measuring participants' (i.e., students, scientist-mentors, and teachers) engagement in an inquiry cycle promoting students' scientific practices and proficiencies.

Research Question 1: According to prominent science education documents and educational practitioner experts, what are major phases of an inquiry cycle?

Research Question 2: Is the instrument reliable and valid that translates the major phases of an inquiry cycle into a checklist and assesses participants' engagement?

Chapter IV entitled "An Exploration and Evaluation of the Inquiry Engagement of Secondary Science Students, Scientists, and Teachers in an Online Learning Environment." The purpose of this exploratory mixed methods study was to evaluate the engagement of students, scientist-mentors, and teachers in an inquiry cycle while using the PS online platform.

Research Question 3: In which phases (e.g., *Immersion*, *Predictions*, *Observation*) of the inquiry cycle do participants provide most evidence for engagement?

Research Question 4: In what sections (e.g., discussion thread, summary, journal) of the PS online platform are participants most likely to engage in during an inquiry cycle?

Chapter V is titled "Does Teacher Workshop Attendance Make a Difference? Comparing Science Students' Interactions in an Online Learning Environment that Promotes the Development of Scientific Practices and Proficiencies." Two different types of teachers participated in PS. One group of teachers attended summer professional development workshops at Texas A&M University; the other group of teachers did not. The purpose of this mixed methods study was to assess and compare students' development of science practices and proficiencies in classrooms led by teachers with and without summer workshop experience. I expected that workshop teachers' extensive PS preparation would benefit their students evidenced by more extensive engagement of these students in an inquiry cycle. I used null hypotheses to perform tests of statistical significance. These null hypotheses stated there would be no differences in students' inquiry performance between workshop and non-workshop teachers. The null hypotheses were:

1. There will be no differences in the number of students' online postings of in workshop and non-workshop teachers' classrooms.
2. There will be no differences between workshop and non-workshop teachers' students in their engagement in the inquiry cycle.

Clarification of Terms

Terms needing clarification are listed below, falling into three major categories: (1) Web-based Platform, (2) Participants, and (3) Inquiry Cycle.

Web-based Platform

***PlantingScience* Innovative Learning System.** The PS learning system combines a web-based platform with face-to-face classroom learning environments and summer professional development workshops.

***PlantingScience* Online Learning Environment.** The PS online learning environment is the portion of PS that occurs online.

Platform. The PS platform is the entire PS online learning environment on the website.

Forum. Forum refers to each student-teams' page on the PS platform. Each student-team has their own place to post information and interact with their scientist-mentor. It is comprised of various sections. (See Appendix A.)

Module. Modules organize the *PlantingScience* plant investigation themes and resources. Each module contains an investigation guide, a mentor tip sheet, a teacher's handbook, guiding questions, recommended resources specific to the module, and general resources. Three modules are open for all participants to use, while five modules are undergoing beta testing. The open modules include: (1) *The Wonder of Seeds*, (2) *The Power of Sunlight*, and (3) *Foundations of Genetics*.

Online Resources. In addition to module-specific related resources, the *PlantingScience* website contains general resources for student-teams, teachers, and scientist mentors. Along with basic documents on how to conduct scientific investigations and navigate the website, resources for teachers and scientist-mentors include a forum where they can asynchronously communicate with each other outside of the student-teams' forums.

Section. A particular area of the Forum where participants can post, various sections are listed below. (See Appendix A.)

Discussion. This section, on the platform, is where student-teams, scientist-mentors, teachers, and other students engage in asynchronous discourse. It is labeled as *Conversation* within a student-team's forum.

Summary. Student-teams can post their research questions, research predictions, experimental design, and research conclusions in this section. It is labeled as *Research Information* in a student-team's forum.

Journal. Students can either upload their individual or student-team journals to this section. It can be found under *Project Data: Our Uploaded Journals* in a student-team's forum.

Data. Student-teams can upload spread sheets and word documents containing raw data, tables, charts, and graphs to this section. It can be found under *Project Data: Our Uploaded Data Files* in a student-team's forum.

Additional. Student-teams, scientist-mentors, teachers, and other students can upload various documents in this section. These documents include final presentations, PDFs, image, audio, and video files.

Participants

Student-team. A student-team typically consists of 2-5 students. Each member of the student-team works together on a single inquiry project and is mentored by a single scientist-mentor.

Scientist-mentor. Plant biologists have the opportunity to mentor students while the students are engaged in conducting a plant-based inquiry project. Each plant biologist is referred to as a scientist-mentor. Each scientist-mentor is assigned one or more student-teams.

Workshop teacher. A workshop teacher has attended one or more of the PS summer professional development workshops.

Non-workshop teacher. A non-workshop teacher has not had the opportunity to attend a PS summer professional development workshop.

Other students. Other students are those who collaborate with and post in student-teams' forums when they are not members of that student-team. Other students are encouraged to read student-teams' forums and collaborate with student-teams.

Inquiry Cycle

Phases. The phases of an inquiry cycle refer to the main stages or categories of an inquiry cycle. Phases are delineated in the checklist developed to assess students' engagement in the inquiry cycle. For purposes of this dissertation there are eight phases of an inquiry cycle. They are (1) *Immersion or Setting the Stage*, (2) *Research Question*, (3) *Prediction*, (4) *Experimental Design and Procedures*, (5) *Observations*, (6) *Analysis and Results*, (7) *Conclusions and Explanations*, and (8) *Future Research and Implications of the Study*. (See Appendix B.)

Element. The term element refers to each evaluative subcategory within a particular phase of the inquiry cycle. (See Appendix B.)

Delimitations and Limitations

PlantingScience (PS) is an innovative learning system engaging students, teachers, scientists, and PS facilitators in many ways in both face-to-face and online interactions. While communication and collaboration could occur between participants in multiple combinations, in this set of studies I did not explore the relationships that occurred within other parts of the PS online platform. For example, teachers, scientists, and PS facilitators collaborated face-to-face and online to develop the PS inquiry modules. In another instance, students and scientists interacted with each other in the online forum only. These same students could also interact face-to-face with each other and their teacher in a classroom. My study focused on the online component of PS and was bound by the information from the records stored on the online platform focused specifically on inquiry cycle engagement within each student-teams' individual forum. Furthermore, students worked in teams and posted together online. As a result, the unit of analysis for my study was student-team rather than individual student.

Though previous studies have examined student engagement in an inquiry cycle, the PS online learning system provides a unique context for student engagement. It is large scale, online, reform-based, and involves the integration of scientist-mentors. Thus approaching the study in Chapter IV from an exploratory perspective was necessary.

There are several limitations to this dissertation. First, only online evidence was examined. Though student-teams and their teachers might have been fully engaged with scientific practices and proficiencies within the face-to-face classroom, my research specifically investigated the online portion of the PS innovative learning system. Furthermore, the instrument developed to evaluate PS was restricted to online use and was not designed to measure face-to-face interactions in the classroom. In addition, this instrument was developed to specifically address the PS learning system. In this system, students conducted plant-based investigations, which were primarily experimental in nature. The instrument, therefore, was not tested with other types of inquiry-based learning systems where different aspects of science could have been emphasized.

Teachers, who attended the PS summer workshops, were individuals that were highly motivated to seek out PD experiences and to take these experiences back to their classrooms. Confounding variables, which I am unaware of or cannot address due to lack of information, might exist between the workshop and non-workshop teachers. These variables include the teachers' backgrounds and professional development experience. These differences, however, are mitigated because non-workshop teachers still had to investigate significant amounts of time and effort to access and implement PS in their classrooms. In addition, due to the timing of the summer workshops, many teachers on the west and east coasts of the United States, who otherwise would have attended, could not because their schools were still in session.

Limitations also existed in sampling design. Only two out of six PS inquiry modules were represented within the study sample, as they were the only ones "ready" with full testing at the time the sample drawn. Furthermore, I used later semesters for my study because the PS platform underwent frequent changes during earlier semesters as it was being developed. As a result of the limitations of my sample, I can only generalize to the student-teams' use of specific modules within certain semesters. Also, the confidence interval was 95% leaving a 5% percent chance for error.

Significance

The study is significant in that it used the context of an exemplary online learning system to (a) inform the design of subsequent online learning systems, (b) support the development of an instrument that assesses students' online scientific practices and proficiencies, (c) provide baseline data regarding participants' use of the online learning system and student outcomes, and (d) ascertain the value of professional development workshops in improving teachers' effectiveness in facilitating the classroom use of online innovative learning systems. Within the scope of the three research studies reported herein, this work makes contributions to a number of stakeholders. For designers of online learning systems, these studies provide evidence for recommendations regarding the scaffolding of website forums. For teachers and scientist-mentors, these studies provide recommendations for scaffolding and assessing student engagement in an inquiry cycle. For the students, these studies can provide recommendations for what they should include in their online postings. For science education researchers, these studies provide a research instrument that can be used to assess and evaluate inquiry-based online engagement developing scientific practices and proficiencies.

These studies also provide baseline information regarding the involvement of various types of participants in an innovative online learning system, providing a database available for further studies. In addition, *PlantingScience* provides evidence that a quality professional development environment is associated with positive student outcomes.

CHAPTER II

REVIEW OF THE LITERATURE

Learning and teaching are no longer bound by the walls of the classroom. Cyberlearning has brought about a revolution among curriculum designers that redistributes time, space, and materials to create anytime, anywhere learning environments. Cyberlearning is used to create innovative learning environments that define new roles for learning materials, classroom learners, teachers, and assessment. Unfortunately, many teachers in the United States haven't gotten the message that new technologies and learning environments mean new strategies for teaching, and for learning. Most teachers and school districts are still bound by traditional learning systems that value teacher-directed instruction, textbook-based curricula, outdated forms of summative assessments, and the notion that learning takes place in a brick and mortar building rather than in the minds of students. While cyberlearning has the potential to change learning systems, it is not the only component. Other components can change outdated learning systems into innovative learning systems.

Available in innovative learning systems but underused are innovative, authentic approaches such as inquiry, which can emphasize science as practice and authentic science research learning. Technology is available that allows for innovative online cyberlearning environments that could facilitate authentic science discourses and practices. The purpose of this literature review is to describe prior investigations related to innovative science learning environments that highlight science as practice, communication that is online and asynchronous, and collaboration among learners within and outside the traditional walls of the classroom.

Systems Thinking

Literature related to innovative learning systems is broad and interconnected, spanning a period of recent time that began with the rise of computers as learning tools. Many literature sources deal with the design of a particular innovative learning system, describing how various forms of cyberlearning technologies have been incorporated into the system to scaffolding learning. Other literature sources focus on scaffolding and the role of various actors (and technology tools) in assisting learners to engage and/or achieve with the innovative learning system. This notion of scaffolding itself has gained in prominence, particularly in the learning sciences literature, with the shift in preferred models of instruction towards learner-centered instruction. Still other literature sources focus on the expansion and/or significance in the educational arena of cyberlearning, which incorporates aspects of both design and scaffolding in describing ranges of learning technologies now available for learners and teachers to use in classrooms. Cyberlearning combines computing and communications in creative ways to enable learners to collaborate without regard to space or time, within and outside the walls of the classroom. As such, the incorporation of cyberlearning technologies into classroom instruction has brought questions to the forefront about the role of teachers, mentors, and peer learners in using these technologies to enhance learning. Literature about cyberlearning-mediated learning environments focuses the designer's lens to creatively employ elements of design with cyberlearning technology and tools to enhance and maximize learning within particular content domains. The goal is often to create engaging learning opportunities for students that are unique to the innovative learning system and restricted by neither time nor space. Creation of these unique learning environments elicits new questions about the role of schooling and traditional instructional models as they are applied in typical classrooms with teachers who may or not understand the difference between learning *about* technology and learning *with* technology. A corpus of literature exists about many aspects of innovative learning systems. Lacking in the literature at this time is much research about innovative and/or authentic assessments of learning within these systems, however. While innovative learning system developers and classroom users intuitively know that benefits exist for learners, traditional notions of pre-post tests and content mastery often prevail. A focus on content mastery in the assessment of student learning within these environments fails to uncover the unique, important outcomes of student learning. Unanswered questions include those about what students really learn in innovative learning systems, whether student outcomes are recognizable and able to be systematically evaluated, and unique contributions of these innovative learning systems to students' repertoires of knowledge and skills prerequisite to their successful functioning as citizens in a rapidly changing, highly technological 21st century world. With this "gap" in the literature substantiated, I set my literature review goals (and ultimate dissertation topic) to investigate student learning outcomes as they occur within innovative learning systems. I chose to identify, assess, and investigate the unique student learning outcomes associated with an innovative learning system, *PlantingScience*, with the goal of contributing to an understanding that currently is lacking in the literature about the unique contributions of innovative learning systems in relation to student learning.

In attempts to arrange my literature review, I began to realize that I needed to develop a learning system for myself in order to create a coherent and cohesive arrangement of the references I have chosen to reflect my reading about various aspects of innovative learning systems. This realization led me to first examine literature from the educational field about systems thinking. If the National Research Council (NRC, 1996) expects that learners will understand how an entire system works and be able to analyze it, then I, too, should be able to employ systems thinking, which "includes understanding how an action, change, or malfunction in one part of the system affects the rest of the system, … [being] able to adopt a holistic perspective of the system" (Houston, 2007). In adopting this perspective, I reasoned that I should begin to understand the complexity of an innovative learning system that goes far beyond simple causal relations that cannot mirror the way that learners within the system actually learn and benefit from it – without avoiding reference to other actors and elements within the system, which may include teachers, peer learners, mentors, and materials.

Systems thinking is complex and multilayered, just as many of my literature sources were. Systems thinking, therefore, would require me, from the literature as my source, to first identify and then investigate the interactions among multiple components and processes that create the emerging and complex phenomenon (NRC, 1996) known as the innovative learning system. Systems thinking experts reminded me that this perspective includes judgment and decision making, systems analysis, and systems evaluation as well as abstract reasoning about how the different elements of a system interact (Peterson, Mumford, Borman, Jeanneret, & Fleishman, 1999). I concluded that approaching this literature review from a systems perspective would allow me to identify, connect, explore, analyze, and evaluate the relationships among salient features of innovative learning systems to better understand their complexity and evolution within a rapidly changing field of education inquiry. Ultimately, the literature review led me to define my purpose in writing this dissertation. My purpose is to apply a systems perspective to make judgments about the unique student learning outcomes of an innovative learning system, *PlantingScience*, with the goal of contributing to an understanding that currently is lacking in the literature.

Innovative Learning Systems

With new understandings about the role of systems thinking in framing my literature review, I first developed a conceptual frame for presenting the literature sources I have chosen to provide the background for the study of any innovative learning system. Figure 2.1 provides the conceptual framework for organizing the literature as well as a general framework for analyzing the features of innovative learning systems in general and specific terms. Note that arrows are double-sided to reflect my reading and understanding that all elements within an innovative learning system are interconnected. Note, also, that the framework identifies five elements, which emerged from my analysis of the literature. These elements are (1) design, (2) scaffolding, (3) cyberlearning, (4) learning environment, and (5) outcomes.

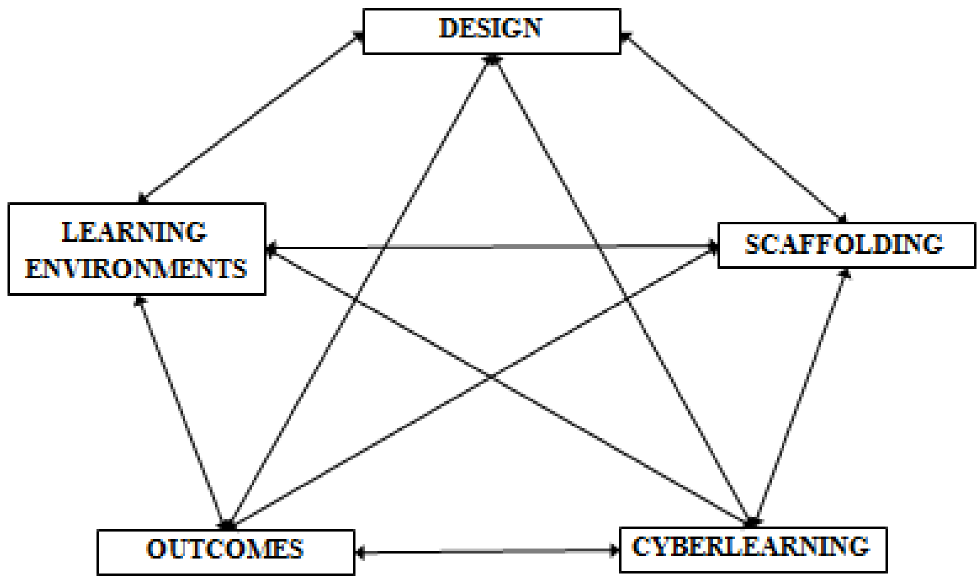


Figure 2.1. Conceptual framework for organizing the literature on innovative learning systems.

I have been able to apply this conceptual framework to generally describe several innovative learning systems. My use of the generalized elements and connections has enabled me to "make sense" of the specific system in terms of conceptualizing the particulars of design, scaffolding, cyberlearning, learning environment, and outcomes. This conceptual framework has also been essential in my thinking about the design of the investigations I will conduct for my dissertation.

The review that follows provides six sections, the first five providing discussions about the five elements of the conceptual framework from the general perspectives of researchers and designers, mainly from the field of the learning sciences, who have made significant and lasting contributions to our general understanding about innovative learning systems. The sixth section focuses on the *PlantingScience* innovative learning system, which links the general elements of innovative learning systems identified in the conceptual framework to the particular learning system that provides the context I have chosen for my dissertation work.

Design

There are two main research groups that provide guiding principles for design that are particularly important in considering the design of authentic science learning systems. Goldman, Petrosino, and the Cognition and Technology Group at Vanderbilt (1999) and Edelson (1998) believe that a learning system should emphasis appropriate goals, proper scaffolding, reflection, and collaboration amongst learners. Goldman et al. (1999) describe four guiding design principles for the development of a learning system, which are integrated together in the learning system. These four principles are:

1. Instruction is organized around meaningful learning and appropriate goals.
2. Instruction provides scaffolds for achieving meaningful learning.
3. Instruction provides opportunities for practice with feedback, revision, and reflection.
4. Instruction is arranged to promote collaboration, distributed expertise, and entry into a discourse community of students (Goldman et al., 1999, p. 603).

Edelson (1997) also has recommendations for design, which incorporates learning about authentic science practice. Edelson's three recommendations include addressing (1) the curriculum structure, (2) teacher preparation, and (3) learner-appropriate resources, tools, and techniques. Edelson notes that some examples of modern curricula may be inflexible in time and topic. These curricula typically do not provide enough time for students to explore topics of personal interest or allow students the opportunity to deal with uncertainty. Teacher preparation typically prepares teachers for traditional teacher-directed instruction instead of innovative approaches such as inquiry-based teaching. The resources, tools, and techniques that expert scientists use need to be adapted for use by novice students in their learning environments. Edelson's (1997) three recommendations can be used in conjunction with the recommendations by Goldman et al. (1999) to create an authentic science learning system that stresses appropriate goals, proper scaffolding, reflection, and collaboration.

A good example of the embodiment of the recommendations and principles of Edelson (1998) and Goldman et al. (1999) is the Learning through Collaborative Visualization (CoVis) project. This project used technology-enhanced computing and communications to support students' visualization of topics related to earth and environmental sciences through collaboration (Edelson 1998). The CoVis project was flexible in that it presented teachers with a set of resources and technologies instead of a fixed curriculum to use in class. Teachers received resources that enabled them to use their own judgment to organize and scaffold their students' learning and learning goals appropriately and meaningfully. These resources and technologies were introduced to teachers during preparatory period designed to familiarize them with non-traditional roles in the classroom and the resources, technologies, and activities that enabled them to use the inquiry-based activities that CoVis offered. These resources and technologies were adapted and scaffolded for students to be able to use meaningfully and effectively. The tools that CoVis offered enabled students to collaborate with each other and engage in discourse with others in their classrooms or different locations. For example, the Collaboratory Notebook allowed students to upload their research questions, hypotheses, plans, various notes, and other resources to their notebooks. Teachers and other students then provided feedback on what the students posted. The posting students' were able revise their work based on their reflections and the feedback they received.

Learning Environments

Important in conversations about innovative learning environments is Brown and Campione's (1996) model for innovative learning environments, which they called Fostering Communities of Learners (FCL). FCL provides "a system of interacting activities that results in a self-consciously active and reflective learning environment" (Brown & Campione, 1996, p. 292). There are three main parts of the FCL environment: (1) research, (2) sharing information, and (3) a consequential task. The students engage both individually and in group research on some facet of an inquiry topic. Students research a topic in order to share information with their classmates and to develop content mastery. The sharing of information about a research topic is motivated by a consequential task (Brown & Campione,1996; Scardamalia, Bereiter, & Fillion,1981) which demands that the students have learned aspects of the topic. There are two additional parts to the FCL environment: (1) reflection and (2) deep disciplinary content. Students reflect about both the research topic and their own learning. This reflection cognitively coordinates the research, sharing of information, and consequential task parts of the FCL innovative learning system. Deep disciplinary content is also an important part of the FCL learning environment since students should develop an understanding of the topic they are researching (Brown & Campione, 1996; Shulman, 1986).

Inquiry in the Classroom Learning Environment

What is inquiry? Inquiry has been "one of the most confounding terms within science education" (Settlage, 2003, p. 34). Inquiry in the classroom has a myriad of meanings. These meanings change depending on the context (e.g. Aulls & Shore, 2008; Grandy & Duschl, 2007; NRC, 1996; NRC, 2000). Though inquiry is a term that is commonly accepted by science education researchers, the definition, appearance, and role of inquiry in the science classroom is widely debated (Abrams, Southerland, & Evans, 2008).

Inquiry has a rich and complex history in the education literature. John Dewey introduced the concept of inquiry in science teaching in the 1920's. Dewey believed that science teaching placed too much emphasis on gathering information and did not place enough emphasis on science as a way of thinking (Bybee, 2000; NRC, 1996). Dewey outlined objectives of teaching science as inquiry. For example, inquiry should develop thinking and reasoning, foster scientific habits of mind, allow for the learning of science content, and construct an understanding of scientific processes.

Another influential figure in shaping our understanding of inquiry, who was exploring classroom inquiry in the 1960's was Joseph Schwab. He believed that teachers and curricular materials presented science in a way that was inconsistent with modern science. Science in the 1960's classroom was being presented as empirical, literal, irrevocable truths. Schwab recommended that science be presented as an inquiry and that students experience inquiry firsthand. Ultimately, he made the case that students could explore scientific phenomena with their own research questions, rather than with questions being given to them by textbooks or their teachers, and that students could also construct their own explanations and arguments for what was occurring (Abrams et al., 2008; Bybee 2000; Schwab, 1966).

The National Research Council (NRC) has also been influential in regard to inquiry and its role in reforming science education (NRC, 1996, 2000, 2007, 2008). The NRC maintains a position that student participation in science is an important goal of science learning and is a way for student to learn science (Abrams et al., 2008). Through reform efforts of organizations such as the NRC, a shift has occurred in the goals of science learning and the roles of students and instructors in the science classroom. This shift allows students to have greater opportunities to engage in and explore scientific phenomena over extended periods of time and develop scientific process skills and habits of mind. The NRC (1996, p. 52) outlines this shift in regards to inquiry in a table that is reproduced below. (See Table 2.1).

Table 2.1
Changing emphases of inquiry

LESS EMPHASIS ON:	MORE EMPHASIS ON:
Activities that demonstrate and verify science content	Activities that investigate and analyze science questions
Investigations confined to one class period	Investigations over extended periods of time
Process skills out of context	Process skills in context
Emphasis on individual process skills such as observation or inference	Using multiple process skills- manipulation, cognitive, procedural
Getting an answer	Using evidence and strategies for developing or revising an explanation
Science as exploration and experiment	Science as argument and explanation
Providing answers to questions about science content	Communicating science explanations
Individuals and groups of students analyzing and synthesizing data without defending a conclusion	Groups of students often analyzing and synthesizing data after defending conclusions
Doing few investigations in order to leave time to cover large amounts of content	Doing more investigations in order to develop understanding, ability, values of inquiry and knowledge of science content.
Concluding inquiries with the result of the experiment	Applying the results of experiments to scientific arguments and explanations
Management of materials and equipment	Management of ideas and information
Private communication of student ideas and conclusions to teacher	Public communication of student ideas and work to classmates

Note. Adapted from the NRC, 1996, *Changing Emphases for Inquiry*, p. 113. Copyright 1996 by the National Academy of Sciences.

Inquiry is a diverse topic with multiple meanings that can be divided three main research contexts: (1) descriptions, (2) abilities and process skills, and (3) teaching. Aulls and Shore (2008) explain that inquiry can be:

1. A description of methods and processes that a scientist uses and a tool that allows students to gain a greater understanding of scientific concepts and principals (Aulls & Shore, 2008, NRC 1996).

2. A set of cognitive abilities and process skills that a student should develop and master (Aulls & Shore, 2008, NRC 1996).

3. A set of pedagogical approaches that can facilitate learning about scientific inquiry, developing the abilities of inquiry, and learning scientific content (Aulls & Shore, 2008).

The National Science Education Standards also describe and integrate three main contexts for inquiry and in addition their perceptions of what inquiry is and the types of activities that students are involved in when engaging in inquiry are also discussed. The NRC (1996) describes inquiry as an activity with many different facets which involves the exploratory process of studying the natural world, making discoveries and then testing these discoveries to develop a deeper understanding. Students engage in inquiry to learn the scientific way of knowing of the natural world around them and to develop the skills and habits of mind to conduct inquiries. In addition, when students engage in inquiry they engage in activities that allow them to develop knowledge and understanding of scientific ideas and how scientists study the natural world. These activities include observing, asking questions, consulting books and other resources to see what is known, planning investigations, reviewing what is already known in light of experimental evidence, using tools to gather, analyze and interpret data, and proposing answers, explanations, and predictions" (NRC, 1996).

Authentic science inquiry. Since Dewey, pressure by educational reformers has increased to have science learning resemble authentic science practice. However, like inquiry, authentic science inquiry has also been defined in the literature in multiple ways. During more recent time periods, technology has become increasingly more complex and accessible to students. According to Chinn and Malhotra (2002), many inquiry tasks given to students are not authentic science inquiry and do not reflect the central attributes of authentic science reasoning. “Authentic science inquiry refers to the research that scientists actually carry out” (Chinn & Malhotra, 2002, p. 177). Edelson, on the other hand, presents a more reasonable position and believes that scientific practice can be successfully adapted to learning environments (1998). Chinn and Malhotra contend that scientific research is a complex activity that uses expensive equipment, is based in elaborate procedures and theories, requires highly specialized expertise, and requires advance data analysis and modeling techniques (2002). Chinn and Malhotra (2002) developed a systematic analysis of authentic science reasoning that is based in the psychology, sociology, philosophy and history of science. This analysis can help accomplish the goal of creating simple inquiry tasks that capture the basic components of scientific reasoning. Edelson (1998) makes a point that technology can be used to aid students in managing these complex activities and help to create inquiry tasks in the classroom that capture the essence of inquiry but are appropriate for students.

Authentic science, according to multiple scientists in a study by Wong and Hodson (2009), can have different objectives such as providing an experience of phenomena and events, demonstrating different ideas, principles or theories, developing skills need for laboratory work, making measurements, determining a relationship, testing hypotheses, manipulating variables, collecting data, or just seeing what can happen. However, theoretical speculation is needed because it allows a person to know what to inquire about, how to do it, and how to interpret the data (Wong & Hodson, 2009).

The process of doing a scientific inquiry requires continuous monitoring and modification. Perfect experiments do not exist. While, the way that science is presented through publication is rigid and step by step, the reality of conducting an authentic inquiry is much more fluid. Scientific endeavors also require creativity and imagination at all stages of an investigation (Wong & Hodson, 2009).

Characteristics of authentic science inquiry. Edelson's research (1998) focused on Authentic Science Learning (ASL) and the incorporation of technology. He believed that the benefits of ASL include students becoming active students, scientific knowledge being acquired in a meaningful context, and students developing styles of inquiry and communication that can enable them to become lifelong students. Incorporating technology can aid in the achievement of these benefits. The characteristics of authentic science practices include attitudes, tools and techniques, and social interaction. Attitudes are divided into uncertainty and commitment. In an authentic learning environment, students must have the opportunity to ask questions that reflect this uncertainty and are meaningful so they remain committed. Tools and techniques in science have been developed over time and are shared through communication. These tools and techniques must be adapted to the classroom in a manner that is reflective of science. Science also includes the communication of results, concerns, and questions to other members of the community.

One of the criticisms of inquiry and other forms of science teaching and learning is that there has been a sharp distinction between scientific processes and content. The NRC (2007, 2008) argues that content and process is linked. When students engage in the process of doing science it strengthens their understanding about both the phenomena and the way that that the phenomena is investigated. As a result the NRC has developed four strands of scientific practices and proficiencies. These four strands encourage students to use, develop, and integrate their (1) knowledge and use of scientific explanations; (2) generate and evaluate scientific evidence and explanations; (3) understand the nature and development of scientific knowledge; and (4) productively participate in scientific practices and discourse (2007, 2008). The four strands are deeply intertwined and cannot be separated from each other.

The inquiry cycle. Dewey envisioned the process of doing inquiry as a series of steps. The steps allowed students to define the problem, make observations, test their ideas, and produce generalizations or predictions (Aulls & Shore, 2008). However, the step-by-step scientific method currently used in classrooms distracts students and instructors from productive inquiry. Students do not have to follow the scientific method to pursue authentic research questions and investigations (Tang, Coffey, Elby, & Levin, 2010).

Within the science classroom, “there is little appreciation of the reflexive nature of experimental design, little recognition that scientists frequently have to engage in revision and reorientation of the procedures in order to overcome initial shortcomings in design" (Hodson, 2009, p. 34). Inquiry is a cyclical and intertwining process. The inquiry cycle is never completely over, yet many of the very textbooks and other resources that are presented to students provide information that appears to be "set in stone". Science and scientific knowledge is tentative and changes based on the development of new information. The different stages of inquiry are also typically taught in a step-by-step fashion instead of a cyclical pattern though this is not reflective of authentic science.

Inquiry teaching can produce positive outcomes (Anderson, 2002) including cognitive achievement, process skills (Shymansky, Kyle, & Alport, 1983), scientific literacy, vocabulary knowledge, conceptual understanding, critical thinking, and attitudes towards science (Haury, 1993). In a synthesis paper, that examined 138 research articles produced during an eighteen-year time span, Minner, Levy and Century (2010), found that instruction within an inquiry cycle increased student content learning. Students who actively engaged in this inquiry cycle by reflecting about it and participating in the investigation process showed an increase in their conceptual learning. According to the authors these findings are consistent with constructive learning theories, which predict that active construction of knowledge through interaction in inquiry is necessary for understanding.

Within the research, scientific, and teaching communities, inquiry does not have a single meaning. The NRC (1996) released a set of standards outlining what students should know and be able to do regarding inquiry; NRC (2000) also recommended that the process of doing inquiry has five essential components. Abrams et al. (2008) did not provide a definitive definition of inquiry but instead explored factors important to inquiry in the classroom. Chinn and Malhotra (2002) provided a strict and seemingly unobtainable definition of authentic inquiry in the classroom, whereas, Edelson proposed a model of authentic inquiry which could happen in the classroom and explored authentic science research learning (1998).

What parts of inquiry are students engaging in? There does not seem to be an instrument which combines the different aspects of inquiry and an inquiry cycle. It could be useful to have an instrument that would examine students' engagement in various parts of the inquiry cycle. This could lead to additional insights of how inquiry appears in the classroom.

Scaffolding

Scaffolding enables students to achieve learning and engage in practices that they would otherwise be unable to do. Wood, Bruner, and Ross (1976) were the first research team to apply the word scaffolding to educational settings. Their definition has been paraphrased by other researchers over the past three decades (e.g. Krajick, Blumenfield, Marx, & Soloway, 1998; Guzdial, 1994; Palinscar, 1998). Wood et al. (1976) used scaffolding in a research project in which they explored interactions between an adult tutor, who provided support, and young children who were building a three-dimensional structure. The type of scaffolding process they described enabled novices to achieve a learning goal which they would not have been able to achieve without the assistance of an adult tutor. The adult controlled the learning goal, which is beyond the student's capabilities at first. This permits the student to focus on the elements that are within her abilities to complete. The result is that the learner learns at a faster pace than she would without an adult.

The notion of scaffolding has expanded past the notion that only an adult can provide scaffolding (Davis & Miyake, 2004; Reiser, 1994). Scaffolding can be provided by others and can also be embedded in technological tools and activities. One way to provide scaffolding is through communication with peers and other types of facilitators. Another way is through computer scaffolding, where the programming takes the place of a facilitator. Scaffolding had previously been used to support an individual learner but now it being used to aid groups of students. A movement amongst those in the learning sciences currently exists that use scaffolding in far more complex settings, such as classroom environments (Davis & Miyake, 2004).

Collaboration as a Form of Scaffolding

Scaffolding can be embedded in technological tools and activities. There has also been a shift from scaffolding individuals to scaffolding groups of students within complex classroom learning environments. One way to provide scaffolding is through communication with peers and other types of facilitators. Another way is through computer scaffolding, where the programming takes the place of a facilitator.

Collaboration can promote active knowledge construction and develop students' socio-cognitive skills (Haythornthwaite, 2006). The role of the teacher within the collaboration can differ from an instructional role where the teacher takes on some of the duties (i.e., dividing team members, project management, and content selection) to one where the students have much more control (Aviv, Erlich, Ravid, & Geva, 2000). When students have more control over their own learning, collaborative learning can be student-centered. Additionally, students are the source of authority and knowledge regarding their assignment and direct a significant amount of the learning (Downing & Holtz, 2008). While students have control over learning, a teacher or facilitator still monitors and provides feedback to the students (Bermejo, 2005).

Collaboration is important in the science profession because it brings together individuals with compartmentalized knowledge bases (Sonnenwald, 2007). Collaboration can create a community of inquiry where students are fully engaged in socially constructing meaningful and worthwhile knowledge (Garrison, 2005).

Proper scaffolding and collaborative interactions with classmates can support student learning in inquiry environments. Technology-based inquiry systems can provide scaffolding and promote collaboration through these carefully scaffolded systems. Some examples of technology-based inquiry environments are ThinkerTools (White & Fredericksen, 1998) and Web-Based Inquiry in the Classroom (Slotta & Linn, 2009). These inquiry systems use multiple types of scaffolding that include programming and collaboration.

ThinkerTools and Web-Based Inquiry in the Classroom (WISE) learning systems provide computer based scaffolding within their technology based learning systems. In ThinkerTools students progress through the carefully scaffolded software by using simulations that become increasingly complex (White & Fredericksen, 1998). A WISE project consists of a number of carefully scaffolded and various steps that are accessed in a predetermined order. These steps include asking a group of students to brainstorm, concept map, reflect on work done in prior portions of the inquiry project, read guiding hints, take assessments, and journal (Slotta & Linn, 2009).

ThinkerTools and WISE also use collaboration as a form of scaffolding. As students engage in the increasingly complex simulations of ThinkerTools, they work collaboratively in groups. The ongoing explanations that they submit are also reviewed by peers within their own classroom (White & Fredericksen, 1998). WISE also promotes student collaboration in groups and peer review. The steps that students engage in are carefully scaffolded to promote the development of a learning community where peer collaboration occurs face-to-face and electronically (Slotta & Linn, 2009).

Mentoring in a Collaborative Learning Environment

Students engaging in project will more likely acquire knowledge and skills about the process of doing inquiry if they have a mentor (Aydeniz, Baksa, & Skinner, 2011; Sadler, Burgin, McKinney, & Ponjuan, 2010). A mentor provides "support and assistance where they are needed for facilitating the development of the protégé. Typically they also model the attitudes and behaviors from which protégés can observe and learn" (Bierema & Merriam, 2002, pp. 212-213). Mentoring can occur face-to-face or at a distance. Differences can occur in the perceptions of mentors and students; mentors typically valued more career-oriented conversations, whereas students valued social behaviors (Bennett, Tsikalas, Hupert, Meade, & Honey, 1998; Young & Perrewé, 2000).

An example of mentoring in a collaborative authentic inquiry environment is provided by Aydeniz et al. (2011). A small group of high school students (n=17) had the opportunity to engage in extended authentic inquiry experiences within scientists' labs under the mentorship and collaborative efforts of research scientists and science graduate students. As a result of engaging in this program, students were able to develop knowledge and skills to conduct their scientific investigations. The students only developed sophisticated understandings about the nature of science if these concepts were explicitly addressed by the scientist-mentor. Also, students' understandings varied depending on the context of their investigations and the mentors' scientific experience. The findings suggest that learning opportunities within these collaborative authentic science inquiry settings must be scaffolded.

Cyberlearning

Cyberlearning is "learning that is mediated by networked computing and communications technologies" (Pea, Borgman, Abelson, et al., 2008, p. 10). This type of learning offers new learning and educational approaches that use networked computing and communication technologies. In addition, learning experiences can occur over time and space. The NSF Task Force on Cyberlearning (Pea et al., 2008) was concerned primarily with student learning *with* cyberinfrastructure instead of learning *about* cyberinfrastructure. The Task Force suggested that cyberlearning takes place in a networked world where learning can occur in a hybrid manner from a variety of sources including personal experiences, education, and collective sources.

The type of communication that can occur has advanced over time. Originally communication was limited to face-to-face interactions. Then waves of technologies occurred that enabled people to communicate with each other over increasing distances and lessened the time it took for communication to occur. Also, the potential for collaboration has increased. Now, the latest advances in communication enable people to collaborate and network over large distances instantaneously, in large numbers, and in very interactive and complex online environments. These advances include cloud computing, Web 2.0, and other forms of collaboration (Pea et al., 2008).

Asynchronous Learning Networks and Communication

Cyberlearning takes place in a networked world where learning is not limited to face-to-face interactions and textbooks. Asynchronous communication (AC) is one mechanism for allowing students, teachers, and scientist-mentors to engage in authentic scientific discourse and collaboration. Occurring at any time and any place there is Internet access, asynchronous communication is convenient for students and facilitators. A computer program stores messages so that other participants can conveniently read and respond to others' comments. In addition to working at any time and in any place, research involving AC provides evidence of advantages to both students and facilitators. The term asynchronous learning networks (ALNs) refer to the integration of these social and technical aspects (Hiltz, Turoff, & Harasim, 2007). Asynchronous Learning Networks (ALNs) are examples of Web 2.0 technologies which promote cyberlearning.

Technologies (i.e., bulletin boards, blogging, texting, instant messaging) are needed to support the asynchronous discourse. However, these technologies are effective only when collaboration occurs from the discourse supported by those technologies. The asynchronous part of ALNs is in reference to the "anytime/anyplace" communication that occurs and the learning networks to the social network that emerges when students and their facilitators collaborate with each other to build and share knowledge (Hiltz, Turoff, & Harasim, 2007).

Benefits of Asynchronous Communication

AC can accommodate different schedules and learning readiness, which is beneficial for students (Hiltz et al., 2007). Due to the increased time during the ongoing conversation, students can think about the posts, consult references, respond, and reflect upon the discussions (De Wever , Schellens, Van Keer, &Valke, 2008; Pena-Shaff & Nicholls, 2004). Additionally, students are able to learn about others' viewpoints and experiences (Kear, 2001). The conversations form a record that can be used for later reflection (Hara, Bonk, & Angeli, 2000; De Wever et al., 2008; Naidu & Järvelä, 2006; MacDonald, 2003). Students are encouraged to reflect on their own perspectives (Harasim, 1993), express their ideas (Hara et al., 2000), and learn from the content of the interactions (Hara et al., 2000; Henry, 1992). When Davidson-Shivers, Muilenburg, and Tanner (2000) compared the quality of synchronous and asynchronous conversations to determine which type of learning environment produced more content-related participation than the other, they found differences. Synchronous dialogue provided a direct and immediate conversation for the responses. However, while asynchronous responses were delayed they were more substantial and focused on content. AC can "promote effective arguments by motivating individuals to build coherent and cohesive explanations in the process of negotiating meanings with peers" (Linn & Slotta, 2006, p. 62). AC is beneficial to students but it can also benefit teachers. The process of collaboration in AC is transparent, and a transcript of students' AC interactions can be used to evaluate both the groups' collaborative process and an individual's contribution (MacDonald, 2003). This feature overcomes a barrier of being able to judge group work fairly. Using a transcript the teacher or researcher can determine the extent to which students engaged each other in negotiating meaning in relation to the scientific material (MacDonald, 2003).

AC can also benefit students who do not actively participate. These lurkers still learn by reading. For example, some students read because they wish to observe others' communication and interactions. Though they might not post they may still be legitimate peripheral participants. Consequently, AC can help these students who are struggling to understand a new topic because it lowers their cognitive and emotional load. If they do not have to post then they can focus on the content without feeling pressured to perform (Dennen, 2008; McKendree, Stenning, Mayes, Lee, & Cox, 1998).

Disadvantages and Limitations of Asynchronous Communication

While asynchronous communication has many advantages it also has disadvantages and limitations. Since students and teachers can access discussion boards at anytime, anyplace and at their own pace, issues regarding time may occur. Posts might not be responded to immediately. It can take minutes, hours or even days before a response is received. The sender can experience anxiety because she might feel that her message was posted incorrectly or other readers might not respond because the message is unworthy of a response (Hiltz et al., 2007). Reading and responding to messages is time consuming and it is difficult to respond to posts immediately (Lin, Hsieh, & Chuang, 2009). As AC removes time restraints, teachers and students perceive that they have ceaseless opportunities to learn and work and thus they can feel overloaded (Hara et al., 2000).

In comparison to face-to-face or vocal communication, asynchronous communication has limited social cues. Posters lack visual cues (Kuehn, 1994) such as gestures and facial expressions and vocal cues such as tone of voice. When these cues are absent posters have to make assumptions about the posts they read and their audience when they respond (Hara et al., 2000). Lurkers can also be problematic. While there are benefits to only watching the online discussions lurking can be perceived negatively. Posters can be confused or angry at lurkers because they do not know if the lurkers agree with the discussions or if the lurkers are reading the discussions, and they may feel that lurkers do not contribute to the discussions (Hara et al., 2000; Dennen, 2008). If posters are graded on their contributions to the discussions then the contributions and learning of lurkers is not present.

Posters can also have difficulties with collaborative skills and the ability to interact in asynchronous discussions. If students are required to contribute to online discussions then additional skills must be acquired such as teamwork and negotiation skills, group decision making and task management (MacDonald, 2003; Schrage, 1990). Students' abilities and competencies to interact online can affect the extent to which their interactions contribute to learning and understanding.

Analyzing Asynchronous Communication

Many studies of AC used exploratory mixed methods techniques that rely heavily on descriptive statistics. They have examined the content of the discussions or both the content and the participant interactions. The content analyses have focused on a variety of subjects including subject matter discussed, metacognition, cognition, social cues, language usage, critical thinking skills, Bloom's Taxonomy, learning outcomes, technology, and knowledge construction. Participant interactions have also been measured in different ways including a basic tallying of number of posts made by individuals, numerical mapping of posts over time, Social Network Analysis, and the mapping of different posts visually.

Henri (1992) was the first researcher who proposed a methodology for examining both content and interaction. Her methodology has provided the foundation for analysis of asynchronous discussions in several of the subsequent studies (e.g., Gunawardena, Lowe, & Anderson, 1997; Guzdial & Turns; 2000; Howell-Richarson & Mellar, 1996). Bloom's taxonomy (Bloom, Engelhart, Furtst, Hill, & Krathwohl, 1956) and Garrison's critical thinking skills (Garrison, Anderson, & Archer, 2000; 2001) have been used repeatedly to analyze the content of the discussions. Social Network Analysis and interaction mapping have provided the means to analyze interaction patterns of the discussions in repeated studies (e.g., Fahy, Crawford, & Ally, 2001; Lipponen, Rahikainen, & Hakkarainen, 2003; Zhu, 2006). Research methodologies that explore AC, however, are diverse, as is the basic unit of analysis of the discussions. Henri (1992) proposed using the unit of meaning to be the unit of analysis for both content and interaction analysis. This has been criticized since the criteria for defining the unit of meaning is vague. Researchers have used multiple ways of defining of the unit of analysis. Most consider the individual message to be the unit of analysis; however, others researchers have defined it in different ways. Howell-Richardson and Mellar (1996) used the speech or illocutionary act, whereas others have used a sentence or paragraph. More recently, researchers have approached the definition of the unit of analysis more dynamically (Hakkarainen & Sintonen, 2002; Schire, 2006; De Smet, Van Keer, & Valcke, 2008). They have used the flexible methodology proposed by Chi (1997), where the grain size for the unit of analysis can vary depending on the research question. Content and interaction analysis of the discussions have also been the focus of the methodology that examines the AC (Schrire, 2003, 2006).

Asynchronous Learning Networks and Collaboration

ALNs promote discourse that benefits both teaching and learning; in addition, ALNs also promotes social cognition (Schrire, 2003). Kim, Hannafin, and Bryan (2007), after reviewing research in technology-supported inquiry classrooms that examined student learning, teacher practices, and classroom environments, concluded that it is “not the innovative technologies per se that have an impact on students’ learning, but the interactive and iterative learning environments” (p. 1025).

Electronic Mentoring

Mentoring is an effective process to aid students in developing skills and attitudes that are necessary for their eventual professions. Mentoring relationships are dependent on frequent and consistent contact, student-centered communication, inquiry-based communication, and discourse that involve both personal and academic topics (Harris, O'Bryan, & Rotenberg, 1996). However, mentoring relationships between students, teachers, and scientists can be difficult to develop because of the constraints of time and distance. Electronic mentoring can support the development of student-mentor relationships because it allows interaction across time and distance (Bonnett, Wildemuth, & Sonnenwald, 2006).

Student-Scientist Partnerships

Participation and discourse are important in conducting authentic scientific inquiries. Participation and discourse in science can also include collaboration. Collaborative activities in inquiries can require students to explain their understandings, engage in argumentation, and critically evaluate the explanations of others. Cyberlearning technologies can allow students to engage in this type of collaborative discourse and participation.

Student-Scientist Partnerships (SSPs) can provide the means for students and scientists to collaborate in authentic science inquiries (Lawless & Rock, 1998; Moss, Koehler, & Rock, 2008). SSPs have a technology-based component, that allow students and scientists to communicate and collaborate with each other. In projects such as GLOBE and Forest Watch (Spencer, Huczek, & Muir, 1998), scientists are partnered with students. The participating students collect data that the scientists can use from all over the world. Data is posted to an online platform and both students and scientists use the posted data for their research analyses. These projects allow students to have a window into authentic science and support via the partnership. However, one of the primary criticisms of these projects is that students are relegated to the role of a technician since they are serving as data collectors and do not experience the fullness of an inquiry cycle (Moss, Koehler, & Rock, 2008). Another type of SSP is the JASON Project, where students can participate and observe the activities that scientists are currently engaged in (Connolly, 2011; Moss, 2003).

In each of the mentioned projects, students do not participate in a full inquiry cycle. These projects lack stages such as immersion and data collection activities, nor are students making the decisions about the inquiries. In addition, students do not engage with scientists through direct asynchronous communication on the online platform. Though these collaborative partnerships contain flaws, there are also benefits. Students, who are novice learners, collaborate with scientists, who are expert learners, albeit indirectly. Scientists have a rich base of content knowledge, are well practiced, have a deeper level of understanding, have greater levels of self monitoring, and start thinking about a scientific problem before they start solving it. This allows them to think about the scientific inquiry more deeply. Scientists who partner with educators can create rich authentic inquiry environments where the students' learning is scaffolded and large databases are created for scientists to use. Working through the inquiry with novices, also enhances the learning of scientists, teachers, and students (Connolly, 2011; Moss, 2003).

While these student-scientist partnerships are promising, they lack the structure and benefits of an ALN. Students who are engaged in the scaffolding of an expert scientist via communication can develop the knowledge and skills necessary to conduct their own scientific investigations (Aydeniz, Baksa, & Skinner, 2011). In addition, these SSPs do not take students through complete inquiry cycles. An ALN which brings together the scientist-mentors and students together while they are engaged in a complete inquiry cycle would be beneficial for student development of scientific practices and proficiencies, which is recommended by the NRC (2007; 2008).

Outcomes

"Assessments should provide teachers and students with timely feedback about students' thinking, and these assessments should support teachers' efforts to improve instruction" (NRC, 2008, p. 151). According to the NRC (2000) formative assessments are important for general guidance and planning. This type of assessment can be used to meet specific learning experiences and goals. However, formative assessments are insufficient in documenting outcomes to questions such as: "What have the students learned? What evidence demonstrates that they are learning? How well are they learning it, and at what level of competence?" (NRC, 2000, p. 76). Summative assessments are needed to determine these types of outcomes.

In addition to researchers, teachers and students should both conduct assessments. Teachers benefit from formative assessment because they better plan and guide their students and they can examine what their students are learning using evidence. Students can benefit from self-assessment. It enables them to reflect on their own learning, and it allows them to become more self-directed in planning, monitoring, and practice.

Slotta and Linn (2009) discuss making thinking visible with different types of assessments. Thinking should be made visible whenever possible within a curriculum. Students in traditional classrooms typically make their ideas visible through assessments such as homework and tests. Innovative learning systems through the use of technology can easily embed assessments. These embedded assessments can allow the teacher access students' ideas more frequently with greater ease. In addition, teachers can see the variety and complexity of students' ideas and more quickly adapt their instruction to the students needs. There are many different ways that students' thinking can become visible such as reflections, making predictions, visually representing their data, writing in journals, synchronous conversations in class, collaborating in a small group in both face-to-face and online settings, and posting information on asynchronous learning networks.

Researchers using WISE have reported that using technology as a tool in making students' thinking visible has resulted in teachers' modifying their instruction to enhance students' learning outcomes, aiding students in analyzing controlled experiments, helping students form connections to real world experiences, drawing students' attention to important and essential information, and enabling students to gain insight into their own thinking (Slotta & Linn, 2009).

Another way of making student thinking visible is through argumentative discourse. The practice of constructing, defending, and revising explanations is essential to students' productive participation in science. Argumentative discourse is "a form of collaborative discussion in which both parties are working together to resolve an issue…" (Andriessen, 2007, p. 443.) According to Berland and Reiser (2009), students can construct and defend scientific explanations by: "(1) using evidence and general concepts to make sense of the specific phenomena being studied; (2) articulating these understandings; and (3) persuading others of these explanations by using the ideas of science to explicitly connect the evidence to the knowledge claims" (p. 29). Assessment of the students' argumentative discourse can uncover the strengths and weakness of the students' scientific explanations that they constructed and defended.

While many teachers embrace technology and new teaching practices they have difficulties when adopting these new technologies and assessing their students' in the new learning systems. Teachers face a steep learning curve. Research into assessing these new learning systems needs to occur along with professional development programs that support teachers as they learn about and engage their students in these new learning systems (Peters & Slotta, 2010).

An Innovative Learning System: PlantingScience

PlantingScience (PS) is a project supported by the Botanical Society of America and the National Science Foundation. The goal of PS is to "improve understanding of science while fostering an awareness of plants" (Hemingway, Dahl, Haufler, & Stuessy, 2011, p. 1535). Expert scientists (scientist-mentors) are made accessible to secondary school classroom students through an online asynchronous communication-based platform. The platform facilitates scientific discourse and collaboration among secondary students, teachers, and scientist-mentors whilst incorporating authentic scientific inquiry into classroom instruction. The outcomes of this type of communication and collaboration can be observed online. As of 2010, over

500 scientists from more than 14 professional plant organizations were volunteering as online scientist-mentors. These scientist-mentors collaborated with over 9000 students spanning 34 states. Furthermore, the PS learning system has also spread internationally (Hemingway et al., 2011).

The *PlantingScience* Innovative Learning System

PS is an innovative learning system. The PS system uses the same design principles of Goldman et al. (1993) and Edelson (1998). The PS learning environment is inquiry-based and uses collaboration between participants as a form of scaffolding. Participants communicate with each other face-to-face in the classroom and on an asynchronous platform online from distant sites. The unique learning outcomes associated with this environment are currently unexplored. (See Figure 2.2.)

Design of *PlantingScience*

PS incorporates the design principles developed by Goldman et al. (1999). First, instruction is organized around meaningful learning and appropriate goals. The learning goal of PS is organized around an improvement in students' understanding of science and plant biology. Participants are immersed in a learning system that promotes the development of scientific practices and proficiencies. Second, instruction provides scaffolds for achieving meaningful learning. Scaffolding is provided not only by the design of the platform but also through the collaboration of the teachers, scientist-mentors, and students in other student-teams. Third, instruction provides opportunities for practice with feedback, revision, and reflection. Student-teams receive feedback

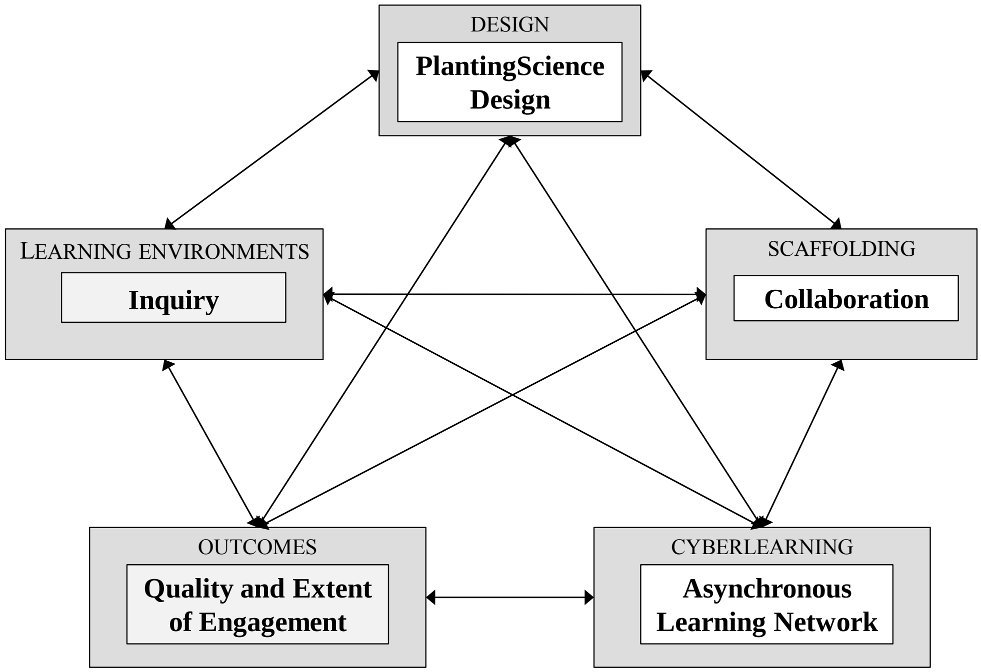


Figure 2.2. A framework for discussing the Innovative *PlantingScience* Learning System, which emphasizes the relationships between the design of *PlantingScience*, inquiry in the classroom, collaboration, an asynchronous learning network, and outcomes.

not only from their face-to-face teachers and peers but also through expert scientists, other students, and other teachers online. The scientist-mentors, other teachers, and other students are able to provide this feedback at a distance. In addition, student teams can revise their projects and upload information based on feedback both online and face-to-face. There is also a permanent record of their correspondence with other participants and their uploaded material, which they can access not only from the classroom but from other locations. This enables student teams to have the ability to use the PS resources and their projects for reflection at anytime and anyplace. Finally, instruction is arranged to promote collaboration, distributed expertise, and entry into a discourse community of students. Collaboration is not only used to scaffold student teams' learning but also for community development. Entry into a scientific learning community is vital for the development of student teams' scientific proficiencies (Hemingway et al., 2011; NRC, 2008). Collaborative scientific discourse is promoted not only in the face-to-face classroom but also online. Student teams are excited to talk online with their scientist-mentors and voluntarily post (Hemingway et al., 2011). In addition, student teams will also post on other student teams' discussion boards furthering the development of an online learning community.

PS also follows Edelson's (1997) design recommendations which includes an emphasis with curriculum structure, teacher preparation, and student-appropriate resources, tools, and techniques.

Curriculum structure. The inquiry-based modules of PS are designed to fit within existing secondary school science curricula. Plant biology is used to teach students basic science knowledge that is required in state and national standards. Modules are flexible, enabling teachers to adapt the plant-based investigations for their students. The modules range from open-ended inquiries to more structured inquiries. PS aims "to shift curricula from repetitive lab exercises with predicable outcomes into the real world of science where ambiguity, messy data, and creativity reside" (Hemingway et al., 2011, p. 1536). (See Figure 2.3.)

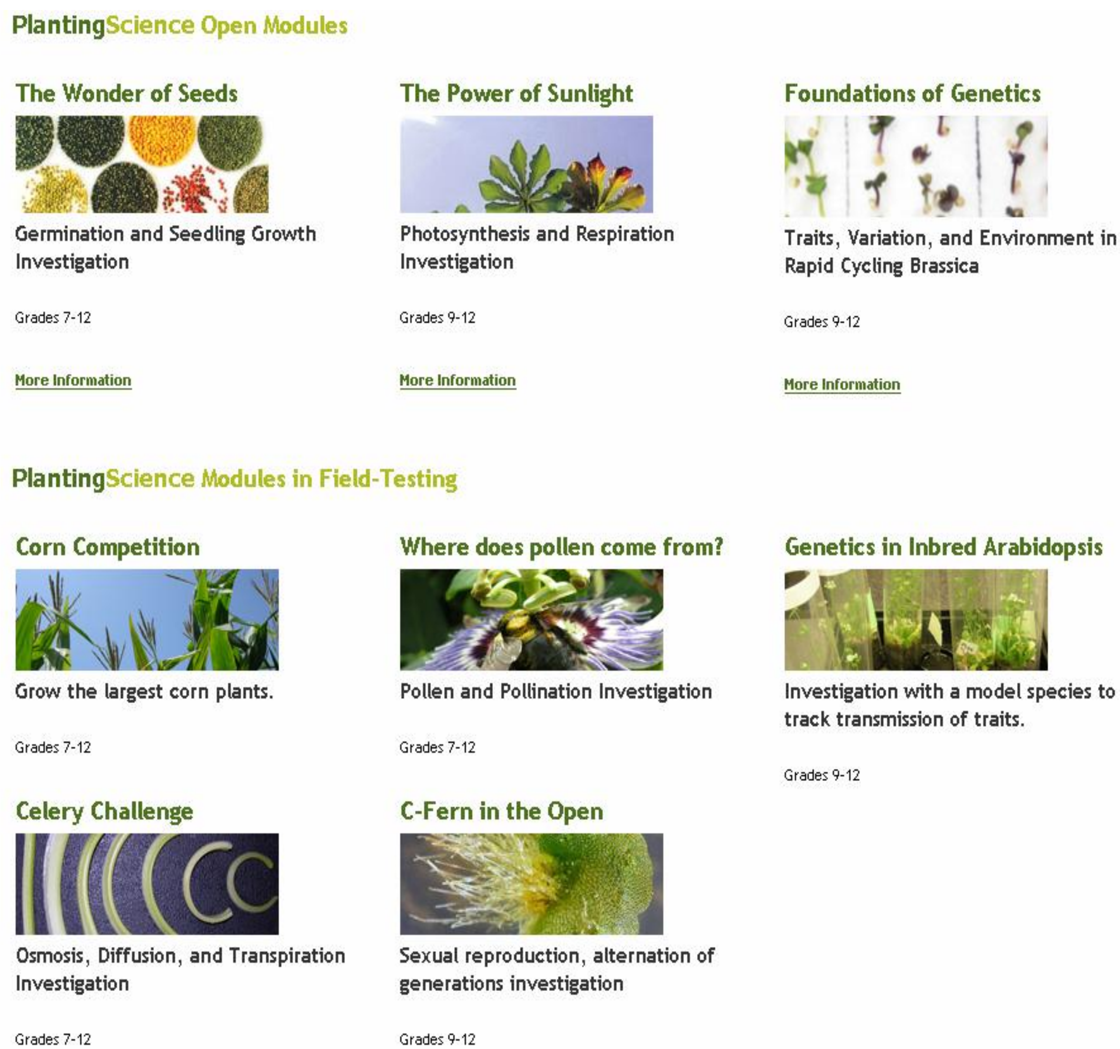


Figure 2.3. A snapshot from the *PlantingScience* online platform that lists the eight modules currently available.

These modules were developed collaboratively between scientists, teachers, and members of the scientific society sponsoring the project. The online collaborative platform serves scientist-mentors, students, and science teachers. Teachers use the platform to integrate modules of instruction with their existing curricular structures; the platform also provides them with access to supporting resources. Students use the platform to make entries into an online scientific journal, post records, summarize their inquiry experiments, and communicate with scientists about their experiments. Scientist-mentors use the platform to provide individualized support and collaboration with the both the students and the teachers during the implementation of these modules.

Teacher preparation. All teachers who use the platform receive preparation and support via online asynchronous communication. They also have access to open-ended curriculum modules and resources that provide ideas for adapting scientific tools, techniques, and investigations to the science classroom learning environment, basic instructions on facilitating online communication between students and scientists and guiding questions. (See Figure 2.4.)

Some teachers have experienced more extensive preparation than others. A few teachers have been involved in the development of the PS modules. These teachers collaborate with the Botanical Society of America (BSA) and scientists to develop the curricula and online platform materials. Some of these teachers field test the newly developed materials in their classrooms. Before and during this process they receive extensive support from the BSA and the scientist involved in the module development via synchronous and asynchronous means.

Some teachers have attended workshops at Texas A&M University, College Station. Nine day workshops were held during the summer in 2008, 2009, and 2010, supporting16 teachers each summer. During the first five days of the workshop teachers

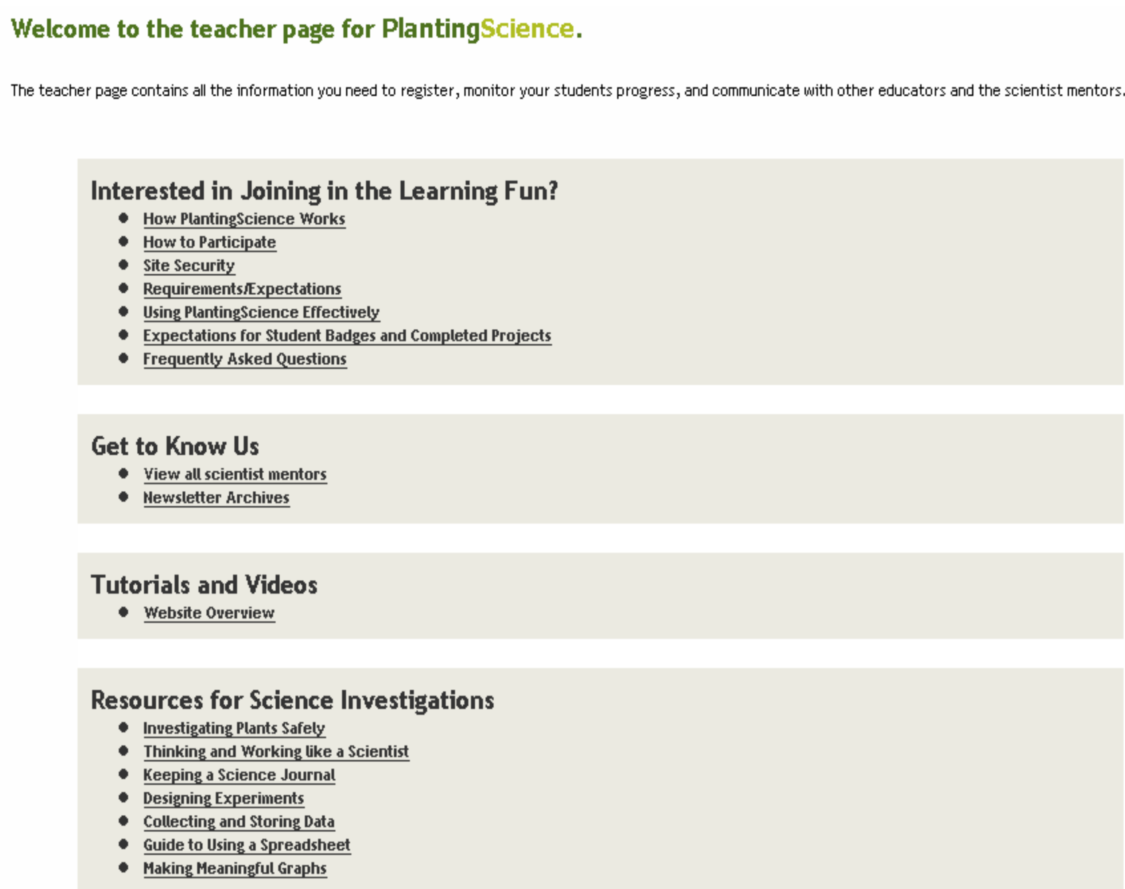


Figure 2.4. A snapshot of the teacher introduction page from the *PlantingScience* online platform.

are led through modules by attending scientists involved in the development of the modules emphasized during the workshop. Workshop teachers are immersed in plant inquiries as learners, while the scientists provide them with an extensive plant content background and familiarize them with interactive tools available on the PS platform. Workshop teachers also “share strategies for using online and classroom discourse and science notebooks as they design an implementation plan for their own students” (Hemingway et al., 2011, p. 1536). Finally, workshop teachers become familiar with the online platform through direct instruction and use of the platform throughout the summer workshop.

Learner-appropriate resources, tools, and techniques. Students participating in PS are provided specific resources. For example, modules are designed to provide students with concepts and inquiry process skills related to plant biology. Scientist-mentors are assigned to collaborate with students teams to choose scientific questions and develop their inquiry projects. Additionally, scientist-mentors provide scaffolding by following students' posts online, providing individualized support, suggestions, and criticisms. In addition to scientist-mentors, students' peers, who attend other classes or schools using this platform, can also provide feedback. Peer input mirrors that received within the larger scientific community. Finally, teachers can also provide feedback to students on the platform, although a more passive approach is recommended to enable students to engage fully with their mentors.

The modules also provide teachers and students with suggestions regarding tools and techniques. Students are exposed to and use tools and techniques that practicing scientists use in their labs, however, these techniques and tools can vary depending on the students' needs. For example in the *Power of Sunlight* module which examines photosynthesis and respiration, several different techniques are discussed and available for students' use (i.e., testing pH using test strips, respirometer, leaf disc flotation, and cell staining).

A Learning Environment of Inquiry

Similar to the Fostering Communities of Learners learning environment (Brown and Campione, 1996), PS provides a learning environment that focuses learning on student research, emphasizes information sharing, and embeds the inquiry cycle within the platform. These actions originate from the student team in the form of a scientific question that is posed and solved by the students. (See Figure 2.5.)

Students engaged in PS have the opportunity to *reflect* and *to share information* about plant science-based inquiry. In addition to the face-to-face discussions, laboratory experiences, and classroom products that students develop, students also generate online information and engage in online discussions. Everything that students share online is accessible and permanent. There are several different locations where students can reflect and share information on what they done. Students can post in the discussion forum and they can reflect on what they have posted and what other students, teacher, and scientist-mentors have posted. Students can also share journals, post data, summarize projects in a summary section, and upload other materials (i.e., videos, presentations, and posters).

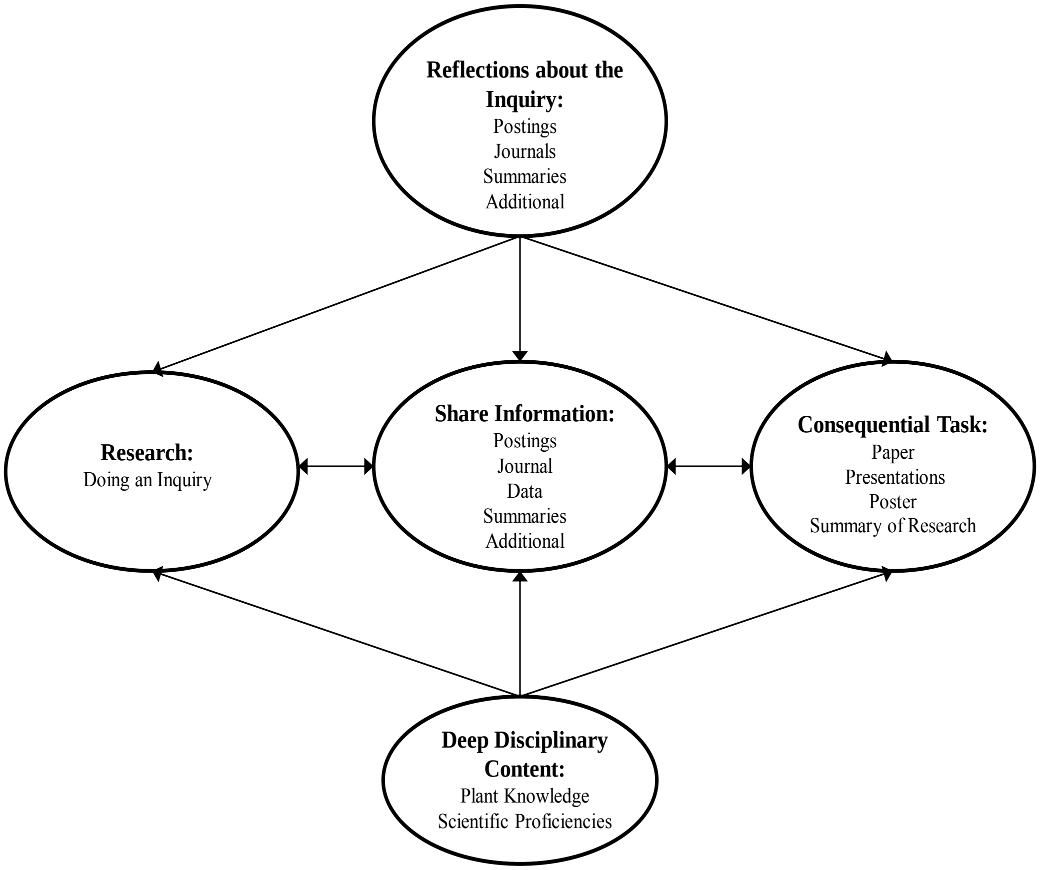


Figure 2.5. Application of the *PlantingScience* inquiry units to the Fostering a Communities of Learners model for learning environments.

PS also promotes authentic scientific *research*. Students have the opportunity to engage in plant science-based inquiry both online and in the classroom. Evidence for research is provided when students share reflections online, share information online, and provide evidence that they completed a *consequential task*. The consequential task is a summative form of assessment, which can include a scientific paper, presentation, poster, or summary of the research in the summary section of the platform.

The final component of the FCL model is *Deep Disciplinary Content*. The type of deep disciplinary content for PS includes plant knowledge and the development and strengthening of students' scientific proficiencies. Evidence for this can be found in the students' posted materials, research information summaries, and their engagement in online discourse.

Cyberlearning and Use of an Asynchronous Learning Network

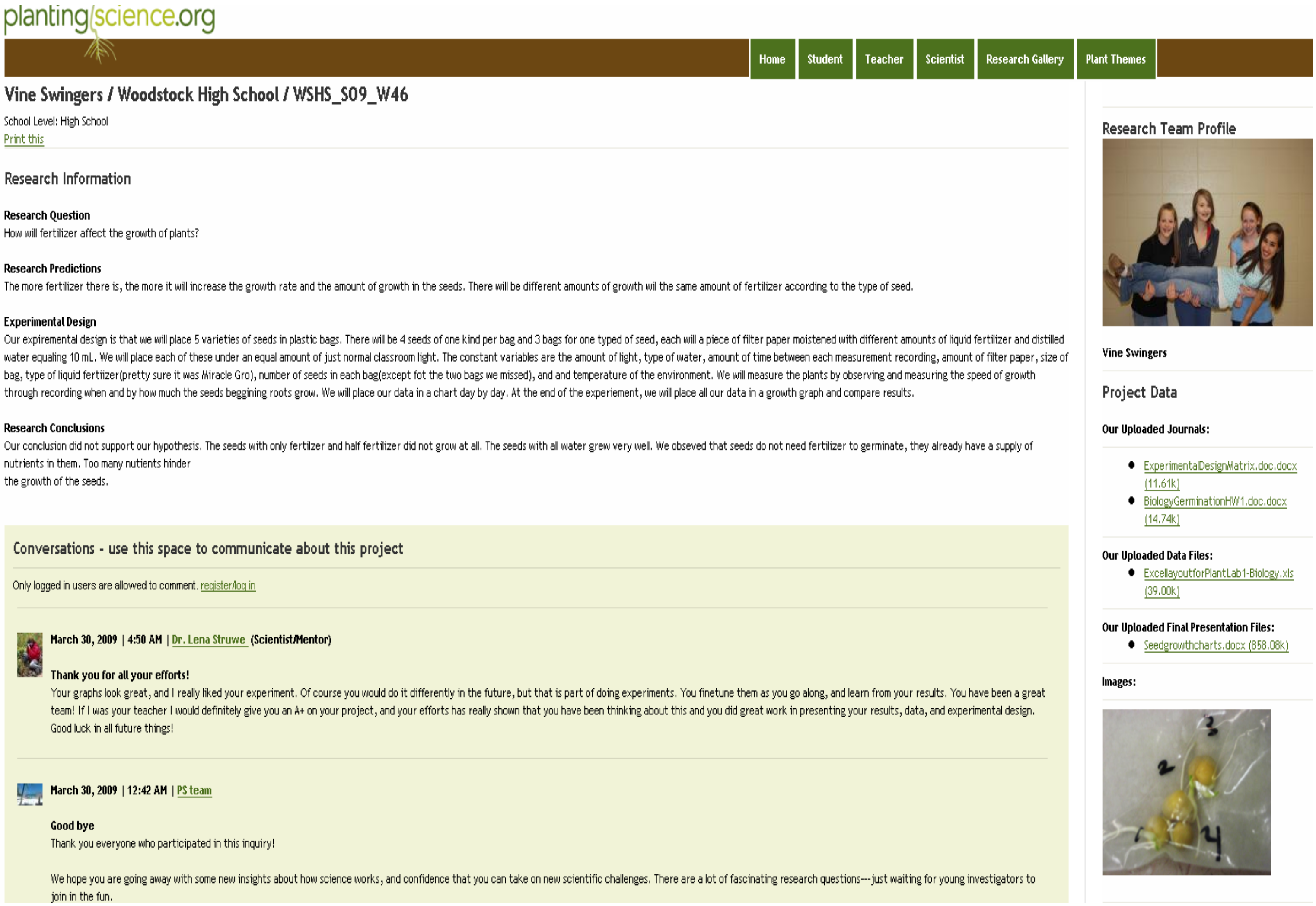
PlantingScience offers students opportunities to engage in both face-to-face teacher and peer interactions along with asynchronous communication with scientist-mentors and peers outside of their classroom. Students can use an asynchronous learning network to share information about their own projects, provide feedback for other peers' projects, access and build a corpus of experience and knowledge that previous participants have constructed, and collaborate online with their scientist-mentors and other peers.

Students can post information in several different ways on the website. Each student group has its own page on which to post their project. They select their team name and post a picture of themselves or another image that is meaningful to them. Near the top of the student team's page there is a *research information* section where they can post summaries of their research questions, predictions, experimental design, and conclusions. On the right side of the student team's page they can post *project data* such as journals, spreadsheets, final presentations, images, and videos. This section provides the scientist-mentors and other students with an alternative view of the students' teams work. The last section of the student teams' page is the discussion board which is called

Conversation. This is where asynchronous conversation occurs. Students, scientist-mentors, teachers, other students, and PS project staff can communicate directly with each other. Scaffolding through online collaboration takes place in this location because the different participants can communicate directly with each other. In addition to this discussion board, the student team can post materials in the research information and project data section that provide additional details and still images/video of their projects. They can do this at the request of the participants reading their forum or proactively upload the information. All of this detail enables the participants, especially the scientist-mentors, to meaningfully and directly scaffold the student teams' scientific discourse and learning. The platform also provides a record that the members of the student team can use to reflect on their own learning. In addition, it provides a resource that other participants can use when they are developing and engaged in their research projects. (See Figure 2.6.)

The PS platform also provides a record of all the communication and students' projects that have occurred. Students, scientist-mentors, and teachers can access previous projects' from 2005-2011 through the research gallery. These participants are able to see various examples of projects from the past and build upon the knowledge that others have constructed previously. This ongoing construction and discussion of scientific knowledge is needed for productive participation within the community and mirrors the types of communication that occur within the scientific community.

Participants are able to search this extensive database in multiple ways. (See Figure 2.7.) They can search the records by semester, grade level, or school. In addition,


plantingscience.org

Home | Student | Teacher | Scientist | Research Gallery | Plant Themes

Vine Swingers / Woodstock High School / WSHS_S09_W46

School Level: High School

Print this

Research Information

Research Question

How will fertilizer affect the growth of plants?

Research Predictions

The more fertilizer there is, the more it will increase the growth rate and the amount of growth in the seeds. There will be different amounts of growth wil the same amount of fertilizer according to the type of seed.

Experimental Design

Our exprimental design is that we will place 5 varieties of seeds in plastic bags. There will be 4 seeds of one kind per bag and 3 bags for one typed of seed, each will a piece of filter paper moistened with different amounts of liquid fertilizer and distilled water equaling 10 mL. We will place each of these under an equal amount of just normal classroom light. The constant variables are the amount of light, type of water, amount of time between each measurement recording, amount of filter paper, size of bag, type of liquid fertiizer(pretty sure it was Miracle Gro), number of seeds in each bag(except fot the two bags we missed), and and temperature of the environment. We will measure the plants by observing and measuring the speed of growth through recording when and by how much the seeds beggining roots grow. We will place our data in a chart day by day. At the end of the experiment, we will place all our data in a growth graph and compare results.

Research Conclusions

Our conclusion did not support our hypothesis. The seeds with only fertilzer and half fertilizer did not grow at all. The seeds with all water grew very well. We obseved that seeds do not need fertilizer to germinate, they already have a supply of nutrients in them. Too many nutients hinder
the growth of the seeds.

Conversations - use this space to communicate about this project

Only logged in users are allowed to comment. register/log in

March 30, 2009 | 4:50 AM | Dr. Lena Struwe (Scientist/Mentor)

Thank you for all your efforts!

Your graphs look great, and I really liked your experiment. Of course you would do it differently in the future, but that is part of doing experiments. You finetune them as you go along, and learn from your results. You have been a great team! If I was your teacher I would definitely give you an A+ on your project, and your efforts has really shown that you have been thinking about this and you did great work in presenting your results, data, and experimental design. Good luck in all future things!

March 30, 2009 | 12:42 AM | PS team

Good bye

Thank you everyone who participated in this inquiry!

We hope you are going away with some new insights about how science works, and confidence that you can take on new scientific challenges. There are a lot of fascinating research questions---just waiting for young investigators to join in the fun.

Research Team Profile

Vine Swingers

Project Data

Our Uploaded Journals:

- ExperimentalDesignMatrix.doc.docx (11.61k)
- BiologyGerminationHW1.doc.docx (14.74k)

Our Uploaded Data Files:

- ExcellayoutforPlantLab1-Biology.xls (39.00k)

Our Uploaded Final Presentation Files:

- Seedgrowthcharts.docx (858.08k)

Images:

Figure 2.6. A snapshot of a student team's *PlantingScience* project page.

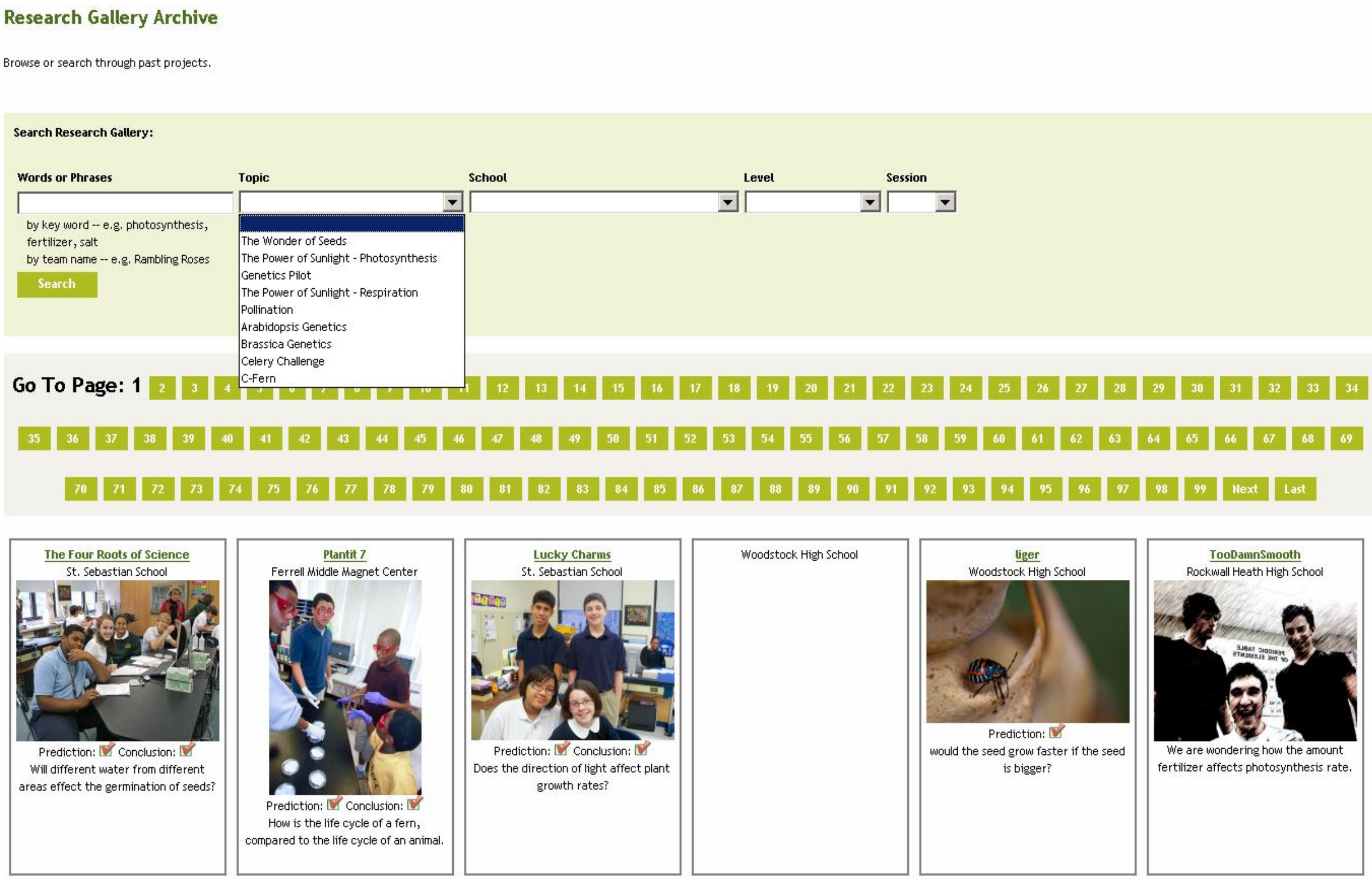


Figure 2.7. Snapshot of the *PlantingScience* research gallery.

participants can enter keywords and search for projects containing these keywords. Also, participants can see examples of projects based on the inquiry module. Teachers can scaffold students' learning by referring their students to previous examples of projects.

Outcomes Associated with the Quality and Extent of Engagement

Opportunities for traditional assessments of the PS innovative learning system were embedded within the PS online system. Pre- and post-tests were administered online by the teacher on the first day of the students' use of an inquiry module and after completion. Teachers selected questions from a list of questions that the PS facilitators developed for each module. The teachers selected the questions according to the learning objectives for their own classrooms. Thus they were able to create tests reflecting their unique classroom. Though students did show positive gains in their attitudes towards science, an analysis of these traditional assessments did not show any evidence of clear gains in the students' metacognitive or inquiry skills (Larson & Stuhlsatz, 2011). These results conflicted with the scientist-mentors' and teachers' positive perceptions of PS. The scientist-mentor and teacher reports indicated that they believed that students' engagement in the PS investigations aided students' education and understanding of science (Larson & Stuhlsatz, 2010).

While PS embeds multiple sources, assessments within the online platform and inquiry modules, researchers have not yet fully realized the potential of these records as evidence for assessment purposes. Students' thinking is made visible in their reflections, predictions, visual representations of their data, journal, synchronous conversations in class, collaborations in small groups in both face-to-face and online settings, posting information on asynchronous learning networks, and their argumentative discourse. Currently lacking, however, are systematic methods to assess the extent of students' learning.

In actuality, the PS online platform provides evidence for both formative and summative assessment purposes. These embedded assessments can allow teachers and scientist-mentors access to students' ideas frequently with great ease. In addition, teachers and scientist-mentors can see the variety and complexity of students' ideas and more quickly adapt their instruction to their students' needs. Teachers and scientist-mentors unobtrusively and without interruption to the flow of students' progress can to conduct formative assessments of their students' progress. Summative assessments can occur after the students have uploaded their research information, journals, data, and final presentations.

The PS online platform provides a record of the students' projects making these projects easy to access long after the individual student teams' projects are complete. The various student products and argumentative and collaborative discourse is available. Research into assessing this new learning system needs to occur. Traditional forms of assessment are insufficient in capturing the complexity of the quality and extent of engagement in the PS learning system.

Putting It All Together

Systems thinking, allowed me to examine literature for my dissertation in such as way that I could meaningfully identify and then investigate the interactions among multiple components and processes that create the emerging and complex phenomenon.

The five components of an innovative learning system emerged as design, learning environments, scaffolding, cyberlearning, and outcomes. Goldman et al.'s (1999) four guiding principles and Edelson's (1998) three recommendations informed my thinking of how to design an innovative learning system. Fostering Communities of Learners (FCL, Brown & Campione, 1996) elaborates by explaining more about the performances of the students with the innovative learning systems. Innovative learning environments provide opportunities for students to reflect on their own learning and develop deep disciplinary content knowledge by engaging in research, sharing information, and completing a consequential task. Authentic science inquiry in the classroom is one example of an innovative learning environment structured along the parameters of FCL. Authentic science inquiry in the classroom learning environment promotes the development of scientific practices and proficiencies. When engaged in authentic science inquiry students are encouraged to use, develop, and integrate their (1) knowledge and use of scientific explanation; (2) generation and evaluation of scientific evidence and explanations; (3) understanding of the nature and development of scientific knowledge; and (4) productive participation in scientific practices and discourse (NRC, 2007; 2008). Carefully scaffolded collaboration, however, is essential to the development of these practices and proficiencies.

Some successful examples of inquiry and collaboration include ThinkerTools and WISE. Research findings suggest that students who engage in these projects have opportunities to complete full inquiry cycles. While these projects use computer technologies to promote collaboration amongst small groups of students, they do not engage students in a discourse community that extends past their classrooms. Student-Scientist Partnerships allow students to contribute to the larger scientific community. However, like the examples of inquiry and collaboration, students do not engage in direct collaborative communication with the very scientists with whom they are working. ALNs are one of the technological tools which can be used to bring students and scientists directly together through the use of asynchronous communication in a setting which promotes collaboration. The *PlantingScience* Innovative Learning System is an environment that integrates innovative design, authentic science inquiry, and collaboration within an asynchronous learning network. Little is known currently, however, about this type of learning system and its impact on students' development of scientific practices and proficiencies as they engage in the mentored inquiry cycles supported by the PS platform. Traditional assessments do not get at the heart of this matter. Instead alternative assessments are needed to understand the quality and extent of students' use of innovative learning systems. *PlantingScience* provides a context in which ideas about authentic assessment can be designed, tested, and evaluated to develop methods for assessing student learning as well as other unique outcomes associated with this particular innovative learning system.

CHAPTER III

DEVELOPING AND VALIDATING AN INSTRUMENT TO MEASURE SCIENTIFIC INQUIRY IN AN ONLINE MENTORED LEARNING ENVIRONMENT

Rationale and Problem Statement

Within innovative technology-based learning environments, little is known about which parts of an authentic scientific inquiry students are likely to engage. Since inquiry has many different meanings, currently an instrument does not exist that combines the different aspects of inquiry within the inquiry cycle that can be demonstrated in an online inquiry learning environment. To examine students' engagement in various parts of the inquiry cycle, an instrument is needed and this instrument can lead to additional insights of how inquiry appears in the classroom.

Literature Review

Scientific inquiry for students can produce positive outcomes (Anderson, 2002), including the development of process skills, cognitive achievement (Shymansky, Kyle, & Alport, 1983), scientific literacy, vocabulary knowledge, conceptual understanding, critical thinking, and positive attitudes towards science (Haury, 1993). However, many issues stand in the way of the use of scientific inquiry in the classroom. First, science inquiry does not have a single meaning. A second issue is the sharp distinction between scientific processes and content, resulting in a number of teachers' misconceptions about teaching inquiry in the classroom at the expense of teaching content. The NRC (2007,

2008) has addressed this issue by proposing that scientific inquiry is best described by strands that link scientific processes with content. Authentic science inquiry is one way that students can engage these scientific practices and proficiencies. Engagement in authentic science inquiry is difficult but it can occur in the classroom through the use of technology. In addition, authentic inquiry is an iterative and cyclical process. However, science inquiry is typically taught in a series of steps which is not reflective of authentic science.

Inquiry has been "one of the most confounding terms within science education" (Settlage, 2003, p. 34). Inquiry in the classroom has a myriad of meanings. The NRC (1996) describes inquiry as an activity with many different facets that involves the exploratory process of studying the natural world, making discoveries and then testing these discoveries to develop a deeper understanding. Students engage in inquiry to learn the scientific way of knowing and to develop the skills and habits of mind to conduct inquiries. In addition, when students engage in inquiry they engage in activities that allow them to develop knowledge and understanding of scientific ideas and how scientists study the natural world. These activities include observing, asking questions, consulting books and other resources to see what is known, planning investigations, reviewing what is already known in light of experimental evidence, using tools to gather, analyze and interpret data, and proposing answers, explanations, and predictions (NRC, 1996).

One of the criticisms of inquiry is the sharp distinction that many educators have made between scientific processes and content. The NRC (2007, 2008) argues that content and process is linked. The NRC developed four strands of scientific practices and proficiencies. These four strands encourage students to use, develop, and integrate their (1) knowledge and use of scientific explanations; (2) generate and evaluate scientific evidence and explanations; (3) understand the nature and development of scientific knowledge; and (4) productively participate in scientific practices and discourse (2007, 2008). The four strands are deeply intertwined and cannot be separated from each other; as such the distinction between scientific processes and content no longer exist.

According to Chinn and Malhotra (2002), many inquiry tasks given to students are not authentic science inquiry and do not reflect the central attributes of authentic science reasoning. "Authentic science inquiry refers to the research that scientists actually carry out" (Chinn & Malhotra, 2002, p. 177). These authors contend that scientific research is a complex activity that uses expensive equipment, is based in elaborate procedures and theories, requires highly specialized expertise, and requires advance data analysis and modeling techniques (2002). They developed a systematic analysis of authentic science reasoning that is based in the psychology, sociology, philosophy and history of science. Chinn and Malhotra's analysis can help accomplish a goal of creating simple inquiry tasks that capture the basic components of scientific reasoning. Edelson believes that scientific practice can be adapted to learning environments (1998). Edelson stresses that technology can be used to aid students in managing these complex activities and help to create inquiry tasks in the classroom that capture the essence of inquiry but are appropriate for students.

Authentic science, according to multiple scientists, can have different objectives such as providing an experience of phenomena and events, demonstrating different ideas, principles or theories, developing skills needed for laboratory work, making measurements, determining a relationship, testing hypotheses, manipulating variables, collecting data, or just seeing what can happen. However, theoretical speculation is needed because it allows a person to know what to inquire about, how to do it, and how to interpret the data (Wong & Hodson, 2009).

Dewey envisioned the process of doing inquiry as a series of steps (Aulls & Shore, 2008). However, the step-by-step scientific method currently used in classrooms distracts students and instructors from productive inquiry. Students do not have to follow the scientific method to pursue authentic research questions and investigations (Tang, Coffey, Elby, & Levin, 2010). Inquiry is a cyclical and intertwining process. The inquiry cycle is never completely over, yet many of the very textbooks and other resources that are presented to students provide information that appears to be "set in stone." Science and scientific knowledge is tentative and changes based on the development of new information. The different stages of inquiry are also typically taught in a step-by-step fashion instead of a cyclical pattern though this is not reflective of authentic science (Wong & Hodson, 2009). Instruction within an inquiry cycle increases student content learning (Minner, Levy, & Century, 2010). Students who actively engage within inquiry cycle by reflecting about it and participating in the investigation process show an increase in their conceptual learning.

Purpose of the Study

The purpose of this mixed-methods study is to describe the development of an instrument measuring participants' (i.e., students, scientist-mentors, and teachers) engagement in an inquiry cycle promoting students' scientific practices and proficiencies.

Research Question 1: According to prominent science education documents and educational practitioner experts, what are major phases of an inquiry cycle?

Research Question 2: Is an instrument that translates the major phases of an inquiry cycle into a checklist and assesses participants' engagement in an inquiry cycle reliable and valid?

Methods

Research Design

This study used an exploratory mixed methods research design to address the development of a valid and reliable instrument which assesses the participants' engagement in an inquiry cycle. This research design was used to first qualitatively explore and identify major sources of science education literature. Coding and categorizing (Chi, 1996) were used to develop a list of inquiry elements reflecting the phases of an inquiry cycle evident in an online authentic scientific inquiry setting. Next, the list of elements was applied to online examples of discourse. As a result, this list was modified. During the second phase of this study the list of elements, which identified the major parts of an inquiry, was developed and refined to assess participants' engagement in an inquiry cycle. The qualitative findings, during the third and fourth phases, were then used to develop a measure that was administered to a collaborative group who had expertise in both the natural and the social sciences and group of scientists who had prior PS mentoring experience. During these final phases, the instrument was further developed and tested and measures of reliability and validity were determined. (See Figure 3.1.)

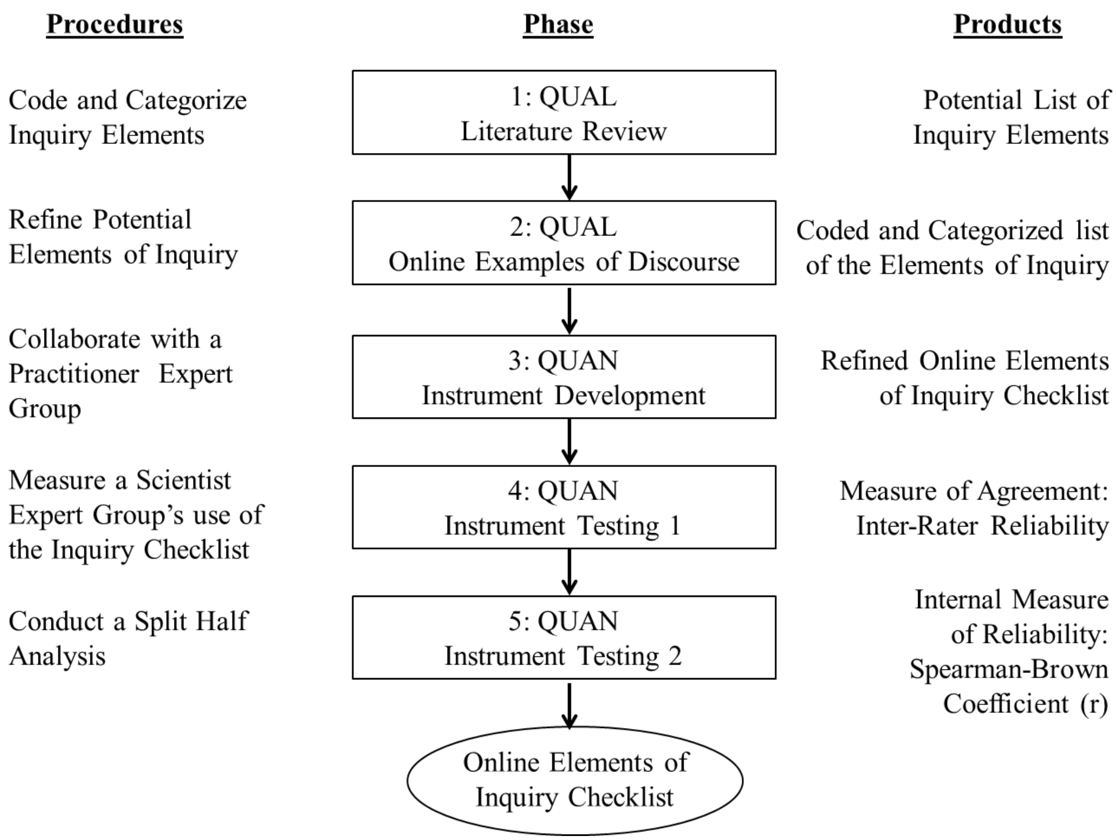


Figure 3.1. Visual model of the exploratory mixed methods study used to develop and validate an instrument for measuring participants' engagement in an online inquiry-based learning environment. (Based on Creswell & Plano-Clark, 2011.)

Question 1: According to prominent science education documents and educational practitioner experts, what are major phases of an inquiry cycle?

During the qualitative portion of this mixed methods study (phases one and two) a literature review was conducted to generate a list of inquiry elements. These inquiry elements were grouped according to major phases of inquiry established within the various literature sources. This list of both major phases and elements of inquiry was refined through a recursive process using random sets of online discourse. A coded and categorized list of inquiry elements and the major phases of inquiry resulted. During the next phase of this study (which is quantitative) the list was distributed to a group of practitioner experts. These experts collaboratively refined the list of inquiry elements and informed the final development of the instrument during multiple sessions.

Question 2: Is an instrument that translates the major phases of an inquiry cycle into a checklist and assesses participants' engagement in an inquiry cycle reliable and valid?

During the final two phases (quantitative) of the research design, the instrument underwent formal tests to determine the instruments' reliability and validity. After the experts had over 95% agreement (phase 3) and had established the content validity of the instrument, the instrument was sent to a group of PS scientist-mentors for (a) pilot testing and (b) determination of inter-rater reliability (phase 4). To confirm the reliability of the instrument, a split half analysis was used. This type of analysis determines the degree of consistency between two halves of the tested results (Tashakkori & Teddlie, 1998). A spilt half analysis was conducted by applying the instrument to 293 student-teams and examining the results of this application. Each inquiry element was assigned a number based on the order it appeared in the checklist. The instrument was split into two halves based on whether the number assigned to each inquiry element was even or odd. The results were then scored. The score of one test was compared to the score of the other half and the reliability was tested (Kaplan & Saccuzzo, 2001).

Findings

Question 1: According to prominent science education documents and educational practitioner experts, what are major phases of an inquiry cycle?

To assess and evaluate participant engagement in an inquiry cycle while using the *PlantingScience* (PS) website, an instrument that could (1) identify the phases of an inquiry cycle that are being discussed or posted about during the online communication between students, scientists, and teachers; (2) measure the quality of online inquiry engagement, and (3) determine which parts of the PS platform are used during the inquiry discussion, was needed. To develop this instrument the major phases of an inquiry cycle needed to be identified along with the components or elements that determine quality engagement.

Phases 1 and 2: Coding, Categorization and Refinement of Inquiry Elements. Reform documents and research articles were used to determine the phases of an inquiry cycle and their elements. The various literature sources each provide different characterizations of science inquiry. Though these characterizations place different emphasizes and priorities on different aspects of scientific inquiry they share many common features (NRC, 2007). The National Science Education Standards

(NSES)(NRC, 1996) and Taking Science to School (TSS)(2007) were the selected reform documents. The NSES document was chosen because it is a collaborative effort between thousands of teachers, scientists, science educators, and other experts across the United States. The NSES advocates that learning science is an inquiry-based process, and it is a comprehensive source that describes the best practices related to inquiry teaching and learning. TSS is another reform document and it synthesizes how students learn the ideas and practices of science. It advocates that science process and science content is linked; this should be emphasized while teaching science. Inquiry-based teaching is a way of linking science process and content.

In addition to reform documents, four articles were selected. The research by Chinn and Malhotra (2002) was chosen because of their emphasis on student engagement in authentic science inquiry. Germman, Haskins, and Auls (1996) provided a comprehensive list of tasks that students should engage in while involved in a scientific inquiry project. Krajcik et al. (1998) researched student engagement in an inquiry cycle and completed an in-depth case study of students involved in scientific inquiry. Although Berland and Reiser (2009) did not address the scientific inquiry cycle, their research was selected because of the emphasis on constructing scientific explanations and participation in argumentative discourse, both of which are important in authentic science inquiry.

Coding and categorizing (Chi, 1996) were used to develop a list of inquiry elements reflecting the phases of an inquiry cycle evident in an online authentic scientific inquiry setting. Information related to inquiry were extracted from the texts and reduced into codes. These codes were then compared and categorized using a constant comparative method (Goetz & Le Compe, 1984). Next, the list of elements was applied to online examples of discourse and modified during the second phase of the research. Phases 1 and 2 of the research resulted in eight main categories or phases of inquiry with 30 sub-categories or elements of inquiry that could assess participants' engagement in an inquiry cycle. The eight phases of an inquiry cycle are: (a) *Immersion* or *Setting the Stage*, (b) *Research Question*, (c) *Prediction*, (d) E*xperimental Design and Procedures*, (e) *Observations*, (f) *Analysis and Results*, (g) *Conclusions and Explanations*, and (h) *Future Research and Implications of the Study*.

Phase 3: Collaboration of a Practitioner Expert Group. Content Validity of the instrument was established through a systematic study of current literature regarding inquiry and the inquiry cycle. Furthermore, a team of six practitioner experts in the natural and social sciences were recruited to develop and refine the instrument along with validating its contents. The earlier versions of the instrument were distributed to a group of practitioner experts. These experts collaboratively refined the list of inquiry elements and informed the final development of the instrument during the course of five sessions. During each of the sessions, the instrument was applied to two to three randomly selected forum examples. The experts then discussed their results and made recommendations on how to refine the instrument. During the last session, the experts were able to apply the checklist to a random sample and achieve over 95% agreement. This resulted in an instrument containing the eight phases of the inquiry cycle from the first two phases of the research design and 40 elements of inquiry.

The Elements of Inquiry that Emerged. The first main phase of inquiry is *Immersion or Setting the Stage*. The five main sources of literature which emphasize the entirety of an inquiry cycle were used to determine and code two elements of inquiry for the *Immersion* phase. (See Table 3.1.) For example, TSS (NRC, 2007) described general staging activities, as activities that provide background knowledge and motivation. Chinn and Malhotra (2002) discussed how scientists' investigations are embedded in existing theories and how scientists select variables to test that are conceptually embedded in these theories. German, Haskins, and Auls (1996) described how prior knowledge has a role in identifying the variables, the relationship between variables, and operationally describing these variables.

The next phase that emerged was *Research Question*. Eight different elements for this phase were generated. These elements ranged from (a) if the research questions that were being asked were appropriate to (b) if the causal research questions that were being asked were testable. Not all of these elements were represented by the five main sources of literature (See Table 3.2.) All of the sources, however, discussed the idea that research questions should focus on variables that are observable or measurable, that the participants should tie the research questions back to prior knowledge or experience, that students should select their own research questions to investigate, that the research questions could be answered within the boundaries of the inquiry setting, and that the research questions are linked to predictions, hypotheses, or expectations. For example,

Table 3.1

Elements of inquiry for Immersion and their corresponding literature sources

Element of Inquiry	Berland and Reiser (2009)	Chinn and Malhotra (2002)	Germann, Haskins & Auls (1996)	Krajcik et al. (1998)	NRC (1996) NSES	NRC (2007) TSS
Is there mention of **information-gathering efforts** (e.g., prior knowledge and/or experiences such as hands-on immersion activities, video- or audio-recordings, demonstrations, readings, discussion with scientists) that occurred before students posed their research question?		X	X	X	X	X
Is there mention of prior knowledge or experiences that enabled the learners to question the **relationships between variables**?		X	X	X	X	X

Table 3.2

Elements of inquiry for Research Questions and their corresponding literature sources

Element of Inquiry	Berland and Reiser (2009)	Chinn and Malhotra (2002)	Germann, Haskins & Auls (1996)	Krajcik et al. (1998)	NRC (1996) NSES	NRC (2007) TSS
Is the research question appropriate for the context of the study?			X	X	X	X
Are variables of interest observable and/or measurable?		X	X	X	X	X
Is there explicit evidence that the research question is tied to prior knowledge or experience?		X	X	X	X	X
Is there evidence that students chose their own research questions?		X	X	X	X	X
Can the research question be answered within the scope and boundaries of the inquiry setting?		X	X	X	X	X
Is the research question logically linked to a prediction, hypothesis, or expectation?		X	X	X	X	X
If the question is causal in nature, is the research question **testable** through a scientific investigation?			X		X	X
If the question is causal, is a relationship between the variables the focus of the research question?			X		X	X

the NSES (1996) would ideally expect students to eventually be able to ask themselves if their research question is the type of question to answer their investigation, to ask questions that are relevant and meaningful to them, to link their research questions to predictions, and ask questions that relate to ideas that can be tested through experimentation. Krajcik et al. (1998) discussed how students should be able to ask themselves if their variables were measurable and are related to the research question and to reflect on the feasibility of answering their research question.

Prediction is the third phase of inquiry in the checklist, and it has three elements. (See Table 3.3.) The first two elements, evidence that students had considered probable outcomes and that they provided evidence that this outcome was based on prior knowledge or experience, were found in all main sources of literature. For example, Krajcik et al. (1998) advocates allowing students to make predictions and allowing them enough time to make these predictions based on their background information. The last element, which was not addressed by all sources, addresses the notion that not only do students provide a predicted outcome, but that this outcome must be reasonable in light of the research question being asked. Krajcik et al. (1998) provided an example of students making a reasonable prediction. These students asked a research question related to bacterial contamination of local water sources, and they predicted that one local river would be more contaminated than the other river nearby due to a greater wildlife population.

Experimental Design and Procedures, containing six elements, was the fourth phase of inquiry that was identified. Not all of the elements were found in the main

Table 3.3

Elements of inquiry for Prediction and their corresponding literature sources

Element of Inquiry	Berland and Reiser (2009)	Chinn and Malhotra (2002)	Germann, Haskins & Auls (1996)	Krajcik et al. (1998)	NRC (1996) NSES	NRC (2007) TSS
Is there evidence that the learners have considered possible or probable outcomes to their investigation?		X	X	X	X	X
Is there evidence that a projected outcome (i.e., prediction, hypothesis, or expectation) is based on prior knowledge or experience?		X	X	X	X	X
Is the predicted outcome reasonable in light of the research question that is being asked?				X	X	X

sources of literature. (See Table 3.4.) Only two of the elements, research design enabled the learner to answer their research question and learners controlled for possible sources of error in their observation, were found in all of the main literature sources. Both TSS (NRC 2007) and Germann, Haskins, and Auls (1996) mentioned that though having controls for variables is important, students are unfamiliar with having a control. In addition, students are rarely asked to provide controls when they are conducting and experiment. The element of inquiry regarding confounding variables was addressed by almost all of the literature sources. TSS discussed the importance of addressing confounding variables, "Confounded experiments, those in which variables have not been isolated correctly, yield indeterminate evidence, thereby making valid inferences and subsequent knowledge gain difficult if not impossible" (NRC, 2007, p. 132). Almost all of the literature sources also stressed the importance of students developing their own research methods. According to Chinn and Malhotra (2002), one of the distinguishing features of authentic science inquiry is that scientists develop their own procedures to address their own research questions. However, only one of the literature sources, Krajcik et al. (1998), addressed the idea that research methods should be in enough detail so that another research group can replicate them.

Observations is the fifth inquiry phase to be described by the instrument, and it contains seven different elements of inquiry. (See Table 3.5.) Not all of the main sources mentioned each element of inquiry. All of these sources, however, emphasized the importance of recording research events and describing what was observed, along with the creation of data tables and visual displays. TSS (NRC, 2007) discussed how

Table 3.4

Elements of inquiry for Experimental Design and Procedures and their corresponding literature sources

Element of Inquiry	Berland and Reiser (2009)	Chinn and Malhotra (2002)	Germann, Haskins & Auls (1996)	Krajcik et al. (1998)	NRC (1996) NSES	NRC (2007) TSS
Did the research design enable the learners to answer their research question?		X	X	X	X	X
Is there evidence that students themselves **developed** research methods?		X	X	X	X	
Is there a description of research methods in enough detail so that another research group could replicate them?				X		
Did the learners mention confounding variables?		X	X	X		X
Are controls of variables mentioned?		X	X	X	X	X
Is there mention that the learners controlled for possible sources of error in their observation methods?		X	X		X	X

important record keeping is and descriptions of observations are during an investigation. In addition, TSS, along with the other sources, emphasized the importance of representing data in multiple ways. However, not all of the sources mentioned the importance of describing and discussing the data representations. TSS was the only document that mentioned the importance of developing visual displays that conform to accepted conventions.

The next phase of the inquiry is *Analysis and Results*. This phase contained four different elements, not all of which were addressed by all of the main sources. (See Table 3.6.) All of the sources addressed two of the elements which involved learners mentioning patterns or trends in the data and unexpected results. The NSES (NRC, 1996) expected learners to be able to ask themselves if there were any surprises from the data. TSS (NRC, 2007) stressed the importance of anomalous data, since this type of data is crucial to scientists because it of its role in changing theory. Some of the literature sources expected learners to compare data across multiple studies. For example, Chinn and Malhotra (2002) discussed how scientists study other scientist research reports for several purposes such as comparing data and coordinating results from multiple studies. Not all of the sources explicitly addressed the idea that data should be used to answer the research question. Though those sources did mention the element, such as the NSES (1996), only some of the sources stressed that students must consider what data will answer their research questions.

Table 3.5

Elements of inquiry for Observations and their corresponding literature sources

Element of Inquiry	Berland and Reiser (2009)	Chinn and Malhotra (2002)	Germann, Haskins & Auls (1996)	Krajcik et al. (1998)	NRC (1996) NSES	NRC (2007) TSS
Is there evidence that research events were recorded?		X	X	X	X	X
Did the learners describe what they observed?		X	X	X	X	X
Are data tables included in the inquiry project?		X	X	X	X	X
Did the learners describe or discuss the data table(s)?			X	X		X
Did the learners provide visual displays of their data such as graphs, charts, or pictures?		X	X	X	X	X
Did the learners describe or discuss the visual displays?			X	X		X
Do the visual displays follow accepted conventions (labels, legends, units of measure, accurate format)?						X

Table 3.6

Elements of inquiry for Analysis and Results and their corresponding literature sources

Element of Inquiry	Berland and Reiser (2009)	Chinn and Malhotra (2002)	Germann, Haskins & Auls (1996)	Krajcik et al. (1998)	NRC (1996) NSES	NRC (2007) TSS
Did the learners mention patterns or trends in the data?		X	X	X	X	X
Did the learners compare data across multiple studies from other student groups?		X	X		X	X
Did the learners mention unexpected results?		X	X	X	X	X
Was the data used to answer the research question?		X		X	X	X

Conclusions and Explanations is the seventh phase and it has eight different elements of inquiry. (See Table 3.7.) Not all of the literature sources included all of the elements, including the research paper by Berland and Reiser (2009). The only two elements that were represented by all of the sources mentioned that learners supported their ideas about causality with data and that learners justified their conclusions using data. Most of the literature sources did mention that learners should connect their conclusion to their data, provide conclusions that are consistent with the data that was collected, mention alternative explanations, compare their results to other studies, discuss the limitations of their research, and begin to develop a model or knowledge claim that explains relationships among variables with the natural phenomenon under investigation. Along with the two elements that all of the sources discussed, Berland and Reiser (2009) also specifically mentioned that an explanation is a claim and though students often make claims, they need help connecting and supporting their claims with evidence; in addition, learners need to make claims that are consistent with their data.

The final inquiry phase is *Future Research and Implications of the Study,* and it contains two elements. (See Table 3.8.) All of the main sources, with the exclusion of Berland and Reiser (2009), discussed the possibility of study revisions. Krajcik et al. (1998) emphasized that it would be valuable for student to be able to redo their research since even scientists have a very difficult time conducting their experiments properly the first time. TSS (NRC, 2007) discussed how students should be able revise their

Table 3.7

Elements of inquiry for Conclusions and Explanations and their corresponding literature sources

Element of Inquiry	Berland and Reiser (2009)	Chinn and Malhotra (2002)	Germann, Haskins & Auls (1996)	Krajcik et al. (1998)	NRC (1996) NSES	NRC (2007) TSS
Are the conclusions of the experiment connected to the data that was collected?	X		X	X	X	X
Are the conclusions consistent with the data that was collected?	X			X	X	X
Did the learners support ideas about causality with data?	X	X	X	X	X	X
Is there mention of alternative explanations?		X	X	X	X	X
Did the learners compare their results to other studies' results?		X	X		X	X
Did the learners discuss the limitations of their research?		X	X			X
Did the learners justify their conclusions using data?	X	X	X	X	X	X
Is there evidence of an expressed model or knowledge claim that explains relationships among variables with the natural phenomenon under investigation?		X	X	X	X	X

Table 3.8

Elements of inquiry for Future Research and Implications and their corresponding literature sources

Element of Inquiry	Berland and Reiser (2009)	Chinn and Malhotra (2002)	Germann, Haskins & Auls (1996)	Krajcik et al. (1998)	NRC (1996) NSES	NRC (2007) TSS
Did the learners discuss the implications of their study?			X	X	X	X
Is there mention of possible study revisions?		X	X	X	X	X

research based on what they learned the first time they conducted the study. All but one source mentioned the other element, which focused on the implications of the study. NSES (NRC, 1996) discussed how studies can sometimes result in new ideas or procedures which can lead to new investigations.

Using the Checklist. During the first meeting the experts asked for operational definitions for each of the inquiry elements and examples from the PS website to help them understand what each element meant and how the evidence could appear on the website. A guide was developed to address the expert group's needs. The definitions for each inquiry element within the guide were developed alongside the instrument as the expert group met.

In addition to establishing the major phases of an inquiry cycle and the various elements of inquiry within each phase, the instrument also classifies what type of participant is fulfilling the inquiry element and where on a website such as PS that the evidence for this fulfillment is found. The inquiry elements represent measures of quality. To receive a checkmark for a specific element the participant needs to have demonstrated evidence of having addressed that element successfully. For example, one of the elements in the *Prediction* phase states "Is there evidence that the learners have considered possible or probable outcomes to their investigation?". To have received a checkmark, the participant must have posted at least one possible outcome on the website. The next element within the *Prediction* phase addressed whether or not the projected outcome is based on prior knowledge or experience. To have received a checkmark for this element, the participant had to have tied her projected outcome to prior knowledge or experience. Thus for the *Prediction* phase, not only should participants post possible outcomes, but they also need to ground these outcomes in prior knowledge or experience.

Four different types of participants use PS: (a) student-team, (b) scientist-mentor, (c) teacher, and (d) other students who are not part of the student-team. The instrument measures the frequency and quality of participants' online engagement within an inquiry cycle. Evidence for engagement in an inquiry element can be found in five different sections on a student-teams' PS forum. These sections are: (a) discussion, (b) journal, (c) data, (d) summary, and (e) additional information. The instrument can also determine where participation is occurring. (See Figure 3.2.) When establishing the 95% agreement, the experts not only examined the examples of forum document for evidence of the various inquiry elements, but they also agreed on who was providing the evidence and the location where the evidence was found.

Future Research and Implications of the Study	Online Evidence								
	Discussant				Source				
	Student	Scientist	Teacher	Other Student	Discussion	Journal	Data	Summary	Additional
Did the learners discuss the implications of their study?									
Is there mention of possible study revisions?									

Figure 3.2. A portion of the checklist which represents the *Future Research and Implications* of the study. There are places to check off if a particular type of participant fulfilled the corresponding element of inquiry and where the evidence was found.

Question 2: Is an instrument that translates the major phases of an inquiry cycle into a checklist and assesses participants' engagement in an inquiry cycle reliable and valid?

During the final two phases (quantitative) of the research design, the instrument underwent formal tests to determine the instruments' reliability and validity. The instrument was named the Online Elements of Inquiry Checklist (OEIC). Accompanying the OEIC, are instructions for using the OEIC, called A Guide to the Online Elements of Inquiry Checklist. This guide contains information regarding the purpose and use of the instrument, operational definitions, and examples from the PS website. See Appendix B for the complete instrument and Appendix C for the guide.

Inter-Rater Reliability. Three PS scientist-mentors were involved in the OEIC's inter-rater reliability assessment. These scientist-mentors were given a copy of the OEIC, the OEIC Guide, and a purposefully selected student-team forum. The student-team forum sample was selected because it was complex, multiple sections of the forum were used, and it had lengthy and interactive discourse. An overall inter-rater reliability of 91.9% was established for the OEIC by these three scientist-mentors. Inter-rater reliability for each inquiry phase ranged from 86.1% for *Prediction* to 100.0% for *Future Research and Implications*. (See Table 3.9.)

Table 3.9
Inter-rater reliability for each inquiry phase of the OEIC

Inquiry Phase	Inter-Rater Reliability (%)
Immersion	96.1
Research Question	93.7
Prediction	86.1
Experimental Design and Procedures	87.5
Observations	87.7
Analysis and Results	90.1
Conclusions and Explanations	94.0
Future Research and Implications	100.0

Split Half Analysis. A spilt half analysis was used to confirm the reliability of the instrument. A split-half analysis is used to determine the degree of internal consistency between two halves of the tested results (Tashakkori & Teddlie, 1998). Using a split half analysis eliminates the need for two administrations of the test, does not require two different forms of the test, and is not affected by changes in an individual being tested over time. The elements of inquiry were numbered 1-40 in the order they appear in the OEIC. The scores for the evenly numbered elements of inquiry were correlated with the scores for the oddly numbered elements of inquiry. A Spearman-Brown Coefficient (r) of .96 was calculated for this instrument, indicating a high level of internal consistency for the OEIC.

Discussion

The Online Elements of Inquiry Checklist (OEIC) (Peterson & Stuessy, 2011) was developed using literature sources such as the National Science Education Standards (NRC, 1996; 2007), Berland and Reiser (2009), Chinn and Malhotra (2002), Germann, Haskings, and Auls (1996), and Krajcik et al. (1998) and the *PlantingScience* student-team forums. The OEIC serves as an instrument to measure participation within an inquiry cycle situated in an online learning system. The OEIC measures the frequency and quality of participants' online engagement within an inquiry cycle. The OEIC, however, is restricted to forum use and is not designed to measure face-to-face interactions in the classroom.

The OEIC is divided into nine sections: (a) *Summary Table*, (b) *Immersion* or *Setting the Stage*, (c) *Research Question*, (d) *Prediction*, (e) E*xperimental Design and Procedures*, (f) *Observations*, (g) *Analysis and Results*, (h) *Conclusions and Explanations*, and (i) *Future Research and Implications of the Study*. These sections represent the nine phases of an inquiry cycle (Peterson & Stuessy, 2011). Each of these sections is divided into various inquiry elements. The OEIC evaluates the role of the students, scientists, students from other teams and schools, and teachers as they communicate using the various online posting options provided by the platform within each student-teams forum. These online posting options include discussion threads, journals, summaries, and additional uploaded documents. See Appendix B for an example of the complete instrument.

Included within the OEIC is the OEIC Guide. This guide explains the purpose for the OEIC, describes the main categories of the OEIC, and discusses the limitations of the OEIC. In addition, each inquiry element from the checklist is operationally defined and supported by authentic examples from the PS website. See Appendix C for the OEIC guide.

The OEIC is a reliable and valid instrument. It was developed during a methodical examination of current and important literature sources that address inquiry. The categories that emerged from this examination were applied to examples of online student, scientist, and teacher engagement in an inquiry project leading to further refinement of the categories. The refined categories became the elements of inquiry. A team of six practitioner experts in the natural and social sciences was recruited to further develop and refine the instrument. The collaborative efforts of this group resulted in the OEIC. This group met several times to establish a 95% agreement regarding the OEIC. Furthermore, an overall inter-rater reliability of 91.9% was established for the OEIC by three scientist-mentors. Inter-rater reliability for each inquiry phase ranged from 86.1% for *Prediction* to 100.0% for *Future Research and Implications*. A spilt half analysis was also used to confirm the reliability of the instrument. This resulted in a Spearman-Brown Coefficient (r) of 0.96, indicating a high level of internal consistency for the OEIC.

The OEIC measures the frequency and quality of participants' online engagement within an inquiry cycle. One of the criticisms of inquiry is the sharp distinction that many educators have made between scientific processes and content. The NRC (2007, 2008) argues that content and process is linked, and as a result, developed four strands of scientific practices and proficiencies. The OEIC can provide insights into how students engage in and interact with these four strands. The four strands allow educators and researchers to examine “how students to use, develop, and integrate their (1) knowledge and use of scientific explanations; (2) generate and evaluate scientific evidence and explanations; (3) understand the nature and development of scientific knowledge; and (4) productively participate in scientific practices and discourse (NRC 2007, 2008). The OEIC measures the quality of students’ engagement in these four strands, including, how students’ productively participate in scientific practices and discourse. This fourth strand is seldom enacted within classrooms. Participants who use *PlantingScience*, which is the online platform that the OEIC was developed to evaluate, participate in discourse. It is this productive participation in science discourse that provides the evidence that is needed to use the checklist.

Summary and Implications

The OEIC is an instrument that integrated various researchers’ visions of inquiry. It combines the different aspects of inquiry and the inquiry cycle that have appeared within literature. It was developed specifically to evaluate inquiry cycle engagement in online learning environments such as *PlantingScience*. Practitioners and researchers alike can use this instrument to explore the quality and extent of participants’ engagement in an inquiry cycle in online learning environments. The OEIC can be used to examine how different types of participants such as students, scientists, and teachers engage in discussion regarding inquiry-based projects. As a result, recommendations of how to engage students in inquiry online can be made to scientists and teachers. In addition, this instrument can serve as a means of determining what section of a platform is being used and how the design of the online learning environment can be altered to facilitate further student inquiry engagement.

CHAPTER IV

AN EXPLORATION AND EVALUATION OF THE INQUIRY ENGAGEMENT OF SECONDARY SCIENCE STUDENTS, SCIENTISTS, AND TEACHERS IN AN ONLINE LEARNING ENVIRONMENT

Rationale and Problem Statement

PlantingScience (PS) is an innovative online learning system where students engage in an authentic inquiry while receiving scaffolding via collaboration with other students, teachers, and scientists. PS participants engage in collaboration across time and distance using an Asynchronous Learning Network (ALN). As a result of cyberlearning technologies, scientists are able to mentor students which can enable students to fully engage in inquiry cycles. However, this type of environment is rare. Many examples of student and scientist collaboration, via technology, focus on Student-Scientist Partnerships (SSPs). While SSPs are promising, most do not allow students to engage fully in inquiry cycles, nor are students' inquiry processes well mentored. PS provides a unique inquiry-based learning system. Currently, little is known about how students, teachers, and scientist-mentors use PS. In addition, traditional forms of assessment have not been effective in capturing the outcomes of PS on its participants. New and innovative ways of assessment are needed.

Literature Review

While using PS students engage in an authentic inquiry while receiving scaffolding via collaboration with other students, teachers, and scientists. Scaffolding enables students to achieve learning and engage in practices that they would otherwise be unable to do. Scaffolding can be provided by others and it can also be embedded within technological tools and activities. Scaffolding has previously been used to support an individual learner but now can be applied to classroom environments (Davis & Miyake, 2004).

Collaboration, an important form of scaffolding in the science profession, brings together individuals with compartmentalized knowledge bases (Sonnenwald, 2007). By bringing individuals together a community of inquiry can be created. Within this community, members can be engaged in socially constructing meaningful and worthwhile knowledge (Garrison, 2005). Technology-based inquiry systems can provide a means for community development while individuals engage within these carefully scaffolded systems.

Within innovative learning environments such as PS, collaboration can occur between students, teachers, and scientist-mentors. Students engaging in projects are more likely to acquire knowledge and skills about the process of doing inquiry if they have a mentor (Aydeniz, Baksa, & Skinner, 2011; Sadler, Burgin, McKinney, & Ponjuan, 2010). Mentors can facilitate the development of protégés, and they also model the attitudes and behaviors (Bierema & Merriam, 2002,). Mentoring can occur face-to-face or at a distance.

Asynchronous Learning Networks (ALNs), such as PS, can provide an online platform which enables students, teachers, and scientist-mentors to engage in authentic scientific discourse and collaboration. However, face-to-face mentoring relationships between students, teachers, and scientist-mentors can be difficult to develop because of the constraints of time and distance. Electronic mentoring using an ALN can support the development of mentoring relationships because it allows interaction across time and distance (Bonnett, Wildemuth, & Sonnenwald, 2006).

Another form of collaboration between students and scientists is a Student-Scientist Partnership (SSP). SSPs allow students and scientists to engage in authentic science inquiries together (Lawless & Rock, 1998; Moss, Koehler, & Rock, 2008). Some SSPs have a technology-based component (e.g., Forest Watch, Project GLOBE) that can allow students and scientists to communicate and collaborate with each other. Students collect data from all over the world, which the scientists can then use. Data is posted to an online platform and both students and scientists use the posted data for their research analyses. However, one of the primary criticisms of these projects is that students are relegated to the role of a technician since they are serving as data collectors and they do not experience the fullness of an inquiry cycle (Moss, Koehler, & Rock, 2008). In projects such as Project GLOBE and Forest Watch, students do not participate in a full inquiry cycle. These projects lack stages such as immersion and data collection activities and students do not make the decisions about the inquiries. In addition, students in these projects do not engage with scientists through direct asynchronous communication on the online platform, nor do they receive mentoring.

While many student-scientist partnerships are promising, without the structure and benefits of an ALN they lose the opportunities for direct collaboration. Students who are engaged in the scaffolding of an expert scientist-mentor via electronic communication can develop the knowledge and skills necessary to conduct their own scientific investigations (Aydeniz, Baksa, & Skinner, 2011). In addition, an ALN that brings scientist-mentors and students together while they are engaged in a complete inquiry cycle would be beneficial for student development of scientific practices and proficiencies, which is recommended by many reform documents (e.g., NRC 2007; 2008).

ALNs, such as PS, are promising. However, difficulties exist in assessing student learning. Traditional pre-post types of assessments do not appear to adequately assess the student outcomes associated with the PS learning environment. While many teachers want to embrace technology and new teaching practices, they have difficulties in adopting these new technologies and assessing their students in the new learning systems. Teachers face a steep learning curve. Research into assessing these new learning systems needs to occur along with professional development programs that support teachers as they learn about and engage their students in these new learning systems (Peters & Slotta, 2010).

Purpose of the Study

The purpose of this exploratory mixed methods study is to evaluate the engagement of students, scientist-mentors, and teachers in an inquiry cycle while using the PS online platform.

Research Question 1: In which phases (e.g., *Immersion*, *Predictions*, *Observation*) of the inquiry cycle do participants provide most evidence for engagement?

Research Question 2: In what sections (e.g., discussion thread, summary, journal) of the PS online platform are participants most likely to engage in during an inquiry cycle?

Methods

Research Design

The purpose of the exploratory two-phase mixed methods design (Creswell & Plano-Clark, 2011) was to evaluate how (a) students, (b) scientist-mentors, and (c) teachers used the PS online platform. This evaluation was done by applying an instrument called the Online Elements of Inquiry Checklist (OEIC). During the first phase of this study (QUAN), selection parameters were determined and a sampling plan was designed and implemented. During the second phase (MIXED), cases were selected for analysis. Specifically, this analysis evaluated (1) in which phases of the inquiry cycle participants provide evidence of engagement and (2) in what sections of use. (See Figure 4.1.)

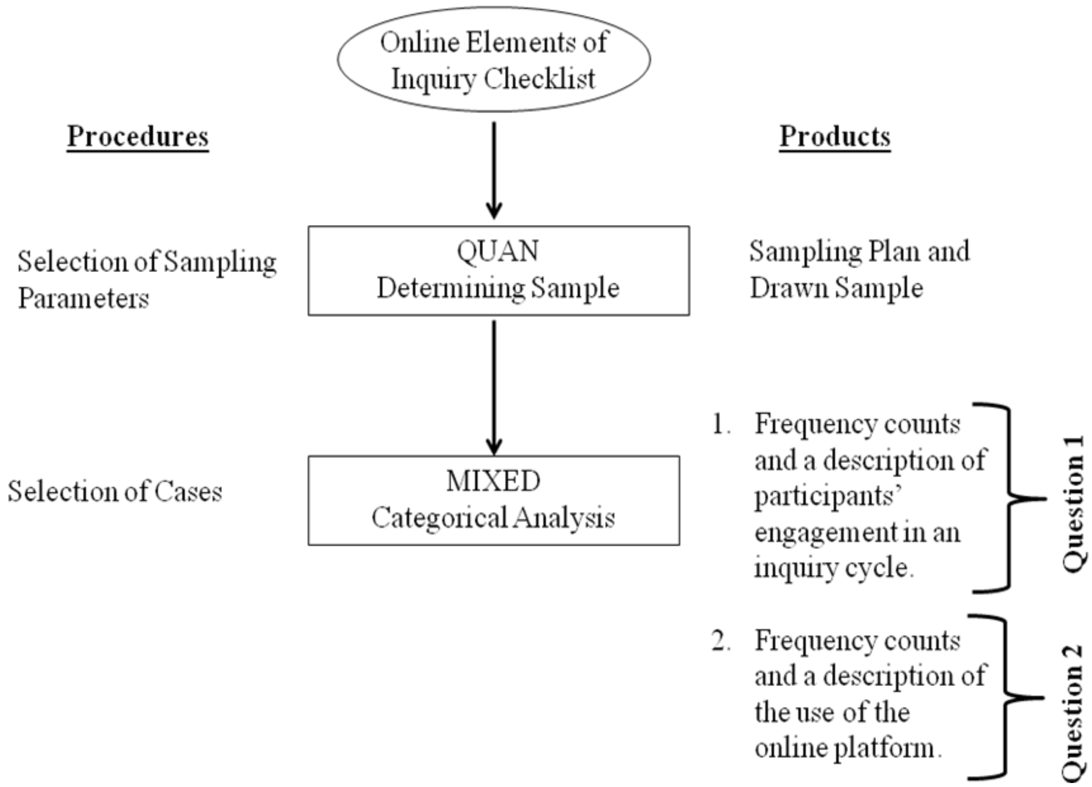


Figure 4.1. Visual model of the exploratory mixed methods study used to explore and evaluate participants' engagement in and use of an online inquiry-based learning environment. Based on Creswell and Plano-Clark, 2011.

Data Sources

To archive participants' use of the PS platform, the Botanical Society of America developed the PS database. This database contains all the records of student-teams, scientist-mentors, and teachers who have participated in PS since 2005. Data includes basic demographic information about teachers, scientist-mentors, and all other participants' use of the online PS platform. The database includes information on the student-teams such as their school name, completion of summary section, name of their teacher, type of module used, and number of posts. However, individual students' actual or full names are not accessible using this database. Information is stored about scientists, including number of years as a mentor, their university, and their chosen discipline. Teacher information includes number of years as a PS teacher, school name, and workshop attendance. Forums from the 263 sampled student-teams were used in the mixed methods analysis. The various posted materials and discourse in all sections of the platform between students, scientist-mentors, and teachers was used to explore and evaluate online engagement in an inquiry cycle.

Sampling Plan

As of 2011, over 900 scientist-mentors and 3,000 student-teams had used the PS platform to engage in plant-based inquiry projects. To assure that my investigations represent optimal yet scientifically accurate results in answering these questions, I developed a plan that allowed me to draw a proportionate and probabilistic sample of student-teams who used the PS platform.

During the first five years (2005-2009) of its existence, a total of 1,287 student teams (N_1) made use of the PS online platform. A sample of student-teams was used to describe and generalize the platforms' effectiveness. Prior to sampling, teams involved during beta testing of the platform's modules and /or those participating as university students were removed. Teams with university level students were removed because this research focuses only on secondary school level students. Student-teams who were beta-testing inquiry modules still in development were removed because there were too many unknown confounding variables that could be introduced to the research sample. The removal of these teams resulted in a true population of 824 student-teams (N_2). To achieve a 5% confidence interval during data analyses, a probability sample of 263 (n_2) student-teams were selected. Using a stratified sampling design, the true population of student-teams was stratified into six exhaustive and mutually exclusive sampling frames. These frames were defined by semester (Fall 2008, Spring 2008, or Fall 2009) and module type, either *Wonder of Seeds* (*WoS*) or *Power of Sunlight* (*PoS*). Within each of these frames, student- teams were listed by student school level (middle or high school). Finally, a proportionate and probabilistic sample of student-teams was selected from each of the six frames (See Figure 4.2, Table 4.1, and Table 4.2). This sampling plan resulted in a sample of 59 *WoS* and 22 *PoS* student-teams from Fall of 2008, 74 *WoS* and 21 *PoS* student-teams from Spring of 2009, and 81 *WoS* and 6 *PoS* student-teams from Fall of 2009.

Wonder of Seeds participants consisted of 214 teams (74 middle school), 41 teachers (9 workshop attendees), and 144 scientist-mentors. Participants using *Power of Sunlight* consisted of 49 teams (one middle school), 13 teachers (5 workshop attendees), and 42 scientist-mentors. Numbers are proportionate to the total number in each selection category.

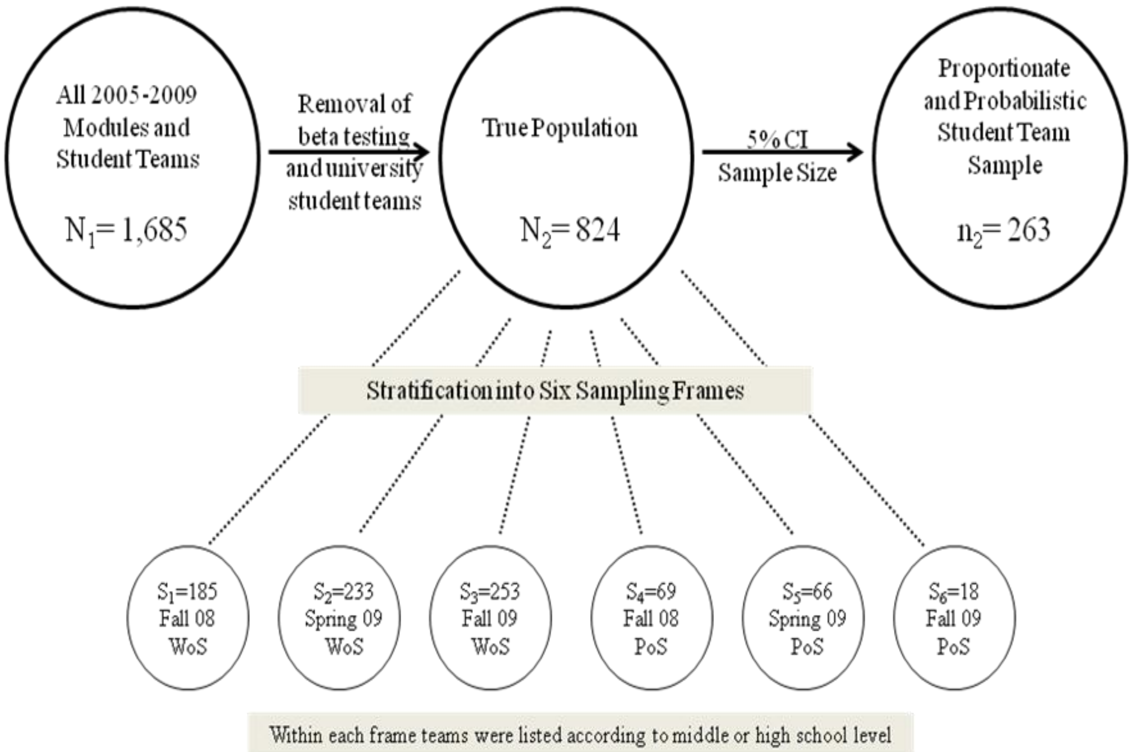


Figure 4.2. Design of sampling plan.

Table 4.1
Distribution of the true population of student-teams according to sample frame (N_2=824)

Module	Fall 08	Spring 09	Fall 09	Total
WoS	185	233	253	671
PoS	69	66	18	153
Total	254	299	271	824

Table 4.2
Distribution of the sample of student-teams according to sample frame (n_2=263)

Module	Fall 08	Spring 09	Fall 09	Total
WoS	59	74	81	214
PoS	22	21	6	49
Total	81	95	87	263

Instrument and Variables

Dr. Carol Stuessy and I developed the Online Elements of Inquiry Checklist (OEIC) (Peterson & Stuessy, 2011) using literature sources such as the National Science Education Standards (NRC, 1996; 2007), Berland and Reiser (2009), Chinn and Malhotra (2002), Germann, Haskings, and Auls (1996), and Krajcik et al. (1998). The OEIC serves as an instrument to measure participation within an inquiry cycle situated in an online learning system. The OEIC measures the frequency and quality of participants' online engagement within an inquiry cycle. The OEIC, however, is restricted to forum use and is not designed to measure face-to-face interactions in the classroom.

The OEIC is divided into nine sections: (a) *Summary Table*, (b) *Immersion* or *Setting the Stage*, (c) *Research Question*, (d) *Prediction*, (e) *Experimental Design and Procedures*, (f) *Observations*, (g) *Analysis and Results*, (h) *Conclusions and Explanations*, and (i) *Future Research and Implications of the Study*. These sections represent the nine phases of an inquiry cycle (Peterson & Stuessy, 2011). Each of these sections is divided into various inquiry elements.

The inquiry elements represent measures of quality. For an element to receive a checkmark from a participant, the participant needs to have demonstrated evidence for having addressed that element successfully. For example, one of the elements in the *Prediction* phase states "Is there evidence that the learners have considered possible or probable outcomes to their investigation?" To have received a checkmark, the participant must have posted at least one possible outcome on the website. The next element within the *Prediction* phase addressed whether or not the projected outcome is based on prior knowledge or experience. To have received a checkmark for this element, the participant had to have tied her projected outcome to prior knowledge or experience. Thus for the *Prediction* phase, not only should participants post possible outcomes but they also need to ground these outcomes in prior knowledge or experience.

The OEIC evaluates the role of the students, scientists, students from other teams and schools, and teachers as they communicate using the various online posting options provided by the platform within each student-teams forum. These online posting options include discussion threads, journals, summaries, and uploaded documents. See Appendix B for an example of the complete instrument.

Included within the OEIC is the *OEIC Guide*. This guide explains the purpose for the OEIC, describes the main categories of the OEIC, and discusses the limitations of the OEIC. In addition, each inquiry element from the checklist is operationally defined and supported by authentic examples from the PS website. See Appendix C for the *OEIC guide*.

A team of six practitioner experts in the natural and social sciences were recruited to develop and refine the OEIC. Additionally, three PS scientist-mentors were involved in the OEIC's inter-rater reliability assessment. An inter-rater reliability coefficient of 92.1% was established for the OEIC by the three scientist-mentors. A spilt half analysis was used to confirm the reliability of the instrument. A split half analysis is used to determine the degree of consistency between two halves of the tested results (Tashakkori & Teddlie, 1998). A Spearman-Brown Coefficient (r) of 0.96 was calculated for this instrument, indicating a high level of internal consistency for the OEIC.

Data Collection and Analysis

Each student-team's forum contains evidence of inquiry engagement from the members of the student-team, a scientist-mentor, the student team's teachers, and other students. Evidence for engagement can be found on various parts of the online forum. Evidence for all 263 sampled student-team forums was analyzed using the OEIC to determine (a) where in the inquiry cycle participants provide evidence of engagement and (b) what parts of the PS platform forum are used by participants.

Question 1: In which phases (e.g., immersion, predictions, observations) of the inquiry cycle do participants provide most evidence for engagement? To determine phases of the inquiry cycle in which participants provide evidence of engagement, results from the 263 sampled student-forums was used. The OEIC enabled me to categorize and quantify the evidence of engagement of each type of participant and the phase in the inquiry cycle in which they participated. Each inquiry phase of the OEIC contains multiple elements. If the participant provided evidence of engagement for an inquiry element, the participant received a check in the appropriate location on the OEIC. Furthermore, other participants may or may not provide evidence of engagement for the corresponding inquiry element. If another participant does so, then she also receives a check mark. Elements provide a way to measure the overall quality of a participants' engagement in a particular phase of inquiry. Each element of inquiry received a value, which was dependent on the number of elements within its inquiry phase. These values were summed and divided by the total number of elements within its inquiry phase, providing a final value of the participants' engagement within an inquiry phase. This type of analysis occurred for each type of participant and their engagement in each phase of an inquiry cycle. Frequency counts were then used to describe engagement in the inquiry participant type and phase. This enabled me to examine trends and describe the participants' engagement within an inquiry cycle.

Question 2. In what sections (e.g., discussion thread, summary, journal) of the PS online platform are participants most likely to engage in during an inquiry cycle? The analysis of Question 2 was similar to the analysis of Question 1. However, instead of generating values for participants' engagement in each phase of the inquiry cycle, the analysis instead enabled me to examine the trends and describe the use of the various sections of the forums. Frequency counts were used to describe the use of each section of the forum during each phase of the inquiry cycle.

The various sections of the forum include discussion, summary, journal, data, summary and additional. They are defined in the following text. Please see Figure 4.3 for a screen shot of a forum example.

Discussion. This section is where student-teams, scientist-mentors, teachers, and other students engage in asynchronous discourse. It is labeled as *Conversation* in a student-team's forum.

Summary. Student-teams can post their research questions, research predictions, experimental design, and research conclusions in this section. It is labeled as *Research Information* in a student-team's forum.

Journal. Students can either upload their individual or student-team journals to this section. It can be found under *Project Data: Our Uploaded Journa*ls in a student-team's forum.

Data. Student-teams can upload spread sheets and word documents containing raw data, tables, charts, and graphs to this section. It can be found under *Project Data: Our Uploaded Data Files* in a student-team's forum.

Additional. Student-teams, scientist-mentors, teachers, and other students can upload various documents in this section. These documents include final presentations, PDFs, image, audio, and video files.

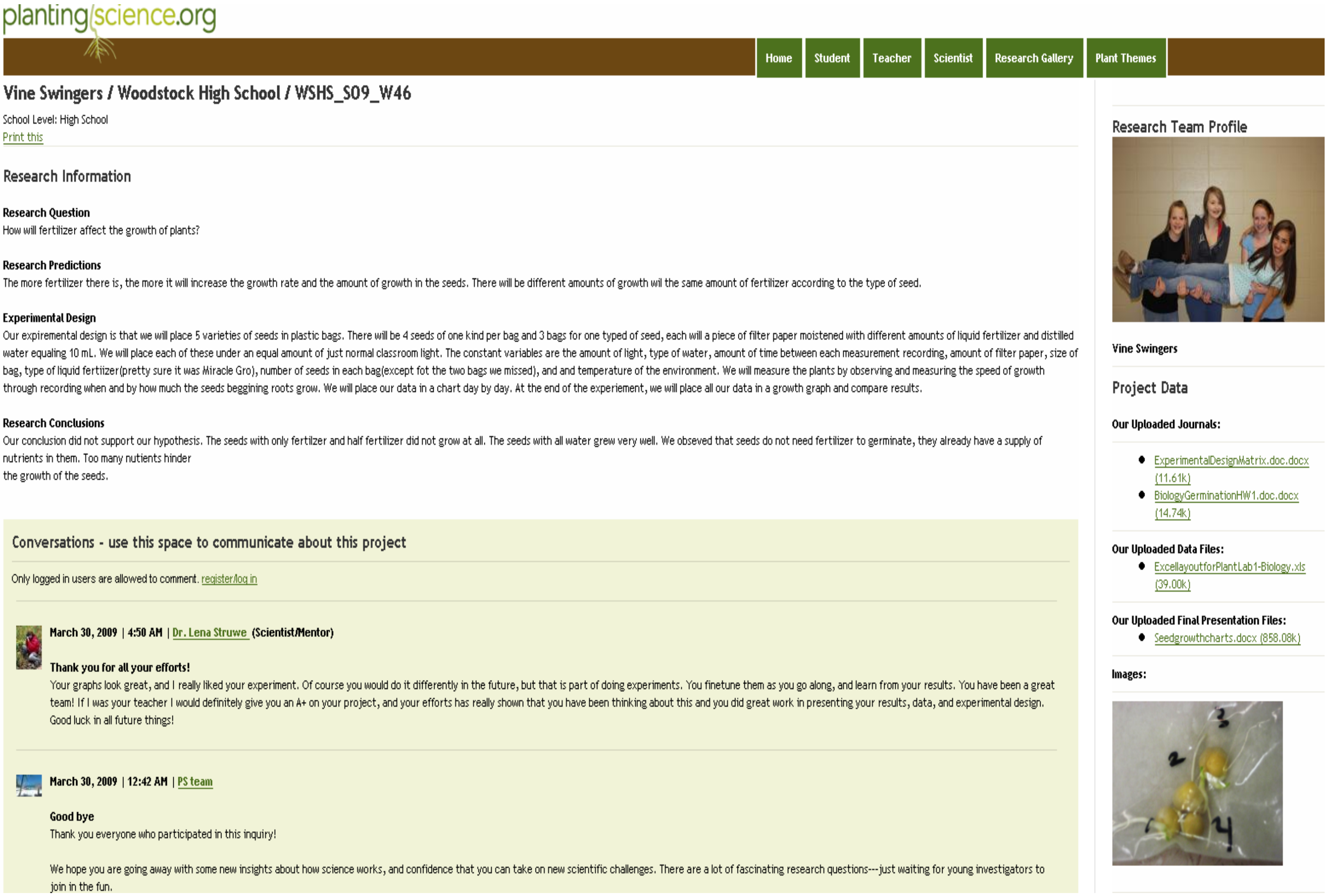


Figure 4.3. An example of a student-team forum.

Findings

Question 1: In which phases (e.g., immersion, predictions, observations) of the inquiry cycle do participants provide most evidence for engagement?

Posting Habits of Participants. Student-teams posted in the discussion section of their forum more often than the other types of participants, with an average of 8.46 posts. The student-teams' scientist-mentors averaged 5.72 posts, teachers averaged 0.47 posts, and other students averaged 1.38 posts. Teachers were the least likely type of participant to engage in the discussion forum. (See Table 4.3.)

Table 4.3
Participants' number of posts

Number of Posts	Student-Team n=263	Scientist-Mentor n=186	Teacher n=44	Other Students n=165
Mean	8.46	5.72	0.47	1.38
Minimum	0	0	0	0
Maximum	44	20	5	12
SD	6.41	3.49	0.93	2.25

Engagement in Inquiry Cycle Phases. The overall findings for each phase of the inquiry cycle were presented along with various elements of inquiry that represent findings of note in this section. The tables containing information regarding the elements of inquiry can be found in Appendix D.

Upon examination of the student-teams (Table 4.4), it appears that student-teams provided the most evidence of quality engagement in the *Research Question* (59.4%), *Prediction* (64.2%), and *Analysis and Results* (44.7%) phases of the inquiry cycle.

When engaged in the creation of research questions, most of the students indicated appropriate research questions (85.9%) and studied variables that were observable and/or measureable (73.8%). There was also evidence that more than half of the student-teams chose their own research questions (51.3%), linked their research questions to predictions, hypotheses, or expectations (58.9%), asked testable research questions (63.9%), and focused on the relationships between variables for their research questions (63.9%). When students were engaged during the *Prediction* phase, many of student-teams considered possible or probable outcomes to their investigations (92.8%), however, they infrequently indicated that their project outcomes were based on prior knowledge or experience (35.4%). Student-teams engaged in the *Analysis and Results* phase typically mentioned patterns or trends in their data (78.7%) but rarely compared their data to other students' results (1.5%).

Less evidence of quality engagement was found in the *Observation* (32.9%), *Immersion* (32.5%), *Conclusions and Explanations* (24.4%), and *Future Research and Implications* (14.3%). During the *Observation* phase, most of the student teams posted descriptions about observation events (72.2%); however, they seldom provided visual displays (35.4%) and data tables (29.7%) or explanations of their data tables (9.1%) and visual displays (9.1%). During the *Conclusions and Explanations* phase, some of the

Table 4.4

A summary of the percent of participants providing quality evidences for each element of inquiry within each section of the checklist

Inquiry Phase	Student-Team n=263	Scientist-Mentor n=186	Teacher n=44	Other Student n=165
Immersion	32.5	30.4	2.1	0.8
Research Question	59.4	20.4	0.9	0.5
Prediction	64.2	29.0	1.0	2.6
Experimental Design and Procedures	34.3	41.8	2.2	2.0
Observations	32.9	11.0	1.5	0.17
Analysis and Results	44.7	16.1	0.8	2.0
Conclusions and Explanations	24.4	12.6	1.1	0.8
Future Research and Implications	14.3	9.7	1.7	1.0

To calculate the above percentages, the average number and percentages of the checked boxes was taken for each of the sections. Weight of each element within a section was assumed to be equal when averaged.

student-teams made conclusions that were connected to (52.1%) and consistent (43.0%) with their data. However, they rarely compared their results to other teams' studies (2.7%) or discussed the limitations of their research (14.8%). Student-teams rarely discussed the implications of their study (5.7%) or considered possible study revisions (22.8%).

Overall, scientist-mentors provided less evidence of quality engagement in the various inquiry phases (see Table 4.4), with the exception of the *Experimental Design and Procedures* (41.8%). Scientist-mentors focused on providing guidance that would enable the student-teams to create a research design that would allow them to answer their research question (70.3%). In addition, scientist-mentors often asked student-teams questions or made comments about replicating the study (52.1%), confounding variables (39.3%), and variable controls (47.9%). They rarely posted about *Observations* (11.0%) and *Future Research and Implications of the Study* (9.7%). When they conversed with the student teams about their observations it was primarily to ask the student teams to describe what they had observed (or to ask if they were recording observations. When the scientist discussed Future Research and Implications of the Study they asked what changes the student teams were thinking of making to their research design.

Teachers and other students rarely provided evidence that they engaged within the various phases of the inquiry cycle. (See Table 4.4.)Teachers contributed most during the *Observation* phase (1.46%). Typically, during this phase, the student-teams' teacher would ask the student to record their observations. Other students, from outside the student-teams' research groups, provided the greatest amount of evidence for engagement during the *Prediction* (2.6%), *Experimental design and Procedures* (2.0%), and *Analysis and Results* (2.0%) phases. Other students would typically ask the student-teams to post their research predictions (3.4%) and to provide more research design detail (4.6%). In addition, other students, would compare their results to the student-teams' results (2.6%) in an effort to engage the student-team in conversation.

Student-Teams Providing Most Evidence of Engagement

Once overall student-team engagement was determined, the top 10% of student-teams were selected. Selection occurred by, examination of each student-teams' total scores (based on the total number of positive responses on the checklist). The examination revealed that student-teams had evenly distributed scores; no natural breaks occurred in the data.

These exemplary student-teams showed differences in posting habits. Their mean number of posts was 14 with a range of 5-44 and a SD of 8.88. Additionally, there were differences in the student-teams' level of engagement in the inquiry cycle. The top 10% of student-teams provided more evidence of quality engagement in each phase of the inquiry cycle. The greatest difference in evidence of engagement between the top 10% of student-teams and all of the student-teams were in *Immersion, Experimental Design and Procedures*, and *Conclusions and Explanations*. The least amount of difference was found in the *Prediction* and *Future Research and Implications* phases. (See Figure 4.4 and Table 4.5.)

Almost all of the top student-teams (88.9%) provided quality evidence that they engaged in *Immersion*; as compared with 32.5% of all student-teams. Almost all of the exemplary student-teams mentioned information gathering efforts (88.9%) and prior knowledge or experiences that allowed them to question the relationships between variables they were going to study (88.9%).

Many (76.6%) of the exemplary student-teams provided quality evidence of engagement in the *Experimental Design and Procedures* phase. They scored higher than all the student-teams did in all of the elements of inquiry for that phase. The greatest difference between the two groups was attributed to the student-teams providing detailed and reproducible research methods (88.9%) and evidence that they developed their own

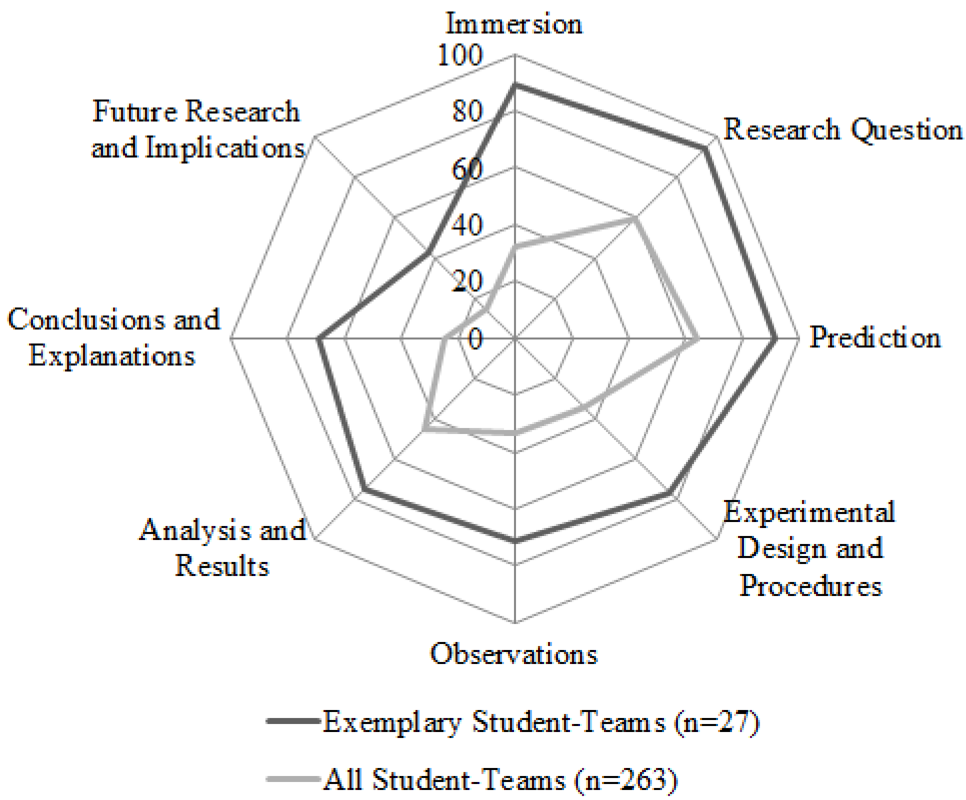


Figure 4.4. Percent of the top 10% of student-teams (n=27) and all the student-teams (n=263) providing evidence of engagement for eight inquiry phases.

research methods (92.6%). All of the exemplary student-teams designed a research projected that enabled them to answer their research questions.

Many of the exemplary student-teams (69.0%) also provided quality evidence of engagement in the *Conclusions and Explanations* phase. The greatest amount of difference between the exemplary student-teams and all the student-teams engagement in the elements of inquiry were in the elements related to connecting the conclusions to

Table 4.5
A summary and comparison of the percent of the top 10% of student-teams (n=27) and all the student-teams (n=263) providing quality evidences for each element of inquiry within each section of the checklist

Inquiry Phase	Exemplary Student-Teams n=27 (%)	All Student-Teams n=263 (%)
Immersion	88.9	32.5
Research Question	93.9	59.4
Prediction	91.3	64.2
Experimental Design and Procedures	76.6	34.3
Observations	71.4	32.9
Analysis and Results	75.0	44.7
Conclusions and Explanations	69.0	24.4
Future Research and Implications	42.6	14.3

To calculate the above percentages, the average number and percentages of the checked boxes was taken for each of the sections. Weight of each element within a section was assumed to be equal when averaged.

the data (top student-team 100%), having conclusions consistent with the collected data (top student-team 92.6%), supporting ideas about causality with data (85.2%), and justifying conclusion using data (81.5%).

The least amount of difference between the exemplary student-teams and all the student-teams were found in the *Prediction and Future Research and Implications* phases. While all of the exemplary student-teams provided evidence that they had considered possible outcomes, almost all of the student-teams did as well (92.8%). The greatest difference between the two groups for this inquiry phase was that many of the exemplary student-teams (81.5%) provided evidence that their predictions were based in prior knowledge or experiences, whereas only 35.4% of all the student-teams did. In the Future Research and Implication phase, over half of the top student-teams (63.0%) mentioned possible study revisions, however, like all of the student-teams, the top student-teams rarely discussed the implications of their study (22.2%).

In regards to lack of evidence provided for an element of inquiry, there were two notable similarities between the top student-teams and all of the student-teams. The student teams rarely mentioned that they controlled for possible sources of error in their observation methods, nor did they compare their data or results to other student groups.

Question 2: In what sections (e.g., discussion thread, summary, journal) of the PS online platform are participants most likely to engage in during an inquiry cycle?

Student-teams and other participants used the various sections of each student-teams' PS forum. (See Table 4.6.) Overall, most evidence for engagement in the inquiry cycle was posted in the Discussion Thread followed by the Summary section of the forums (*Experimental Design and Procedures, Analysis and Results, Conclusions and Explanations,* and *Future Research and Implications*). Evidence for *Immersion* was found primarily in the Discussion thread but was also contained in the Journal section. During the *Research Question* and *Prediction* phases, evidence of quality engagement was found more often in the Summary section than in the Discussion Thread. The Observation phase was the only phase where a significant amount of evidence for inquiry engagement was found in the Data section. The Journal and Additional sections had sporadic postings providing quality evidence of engagement.

Table 4.6

A summary of the percent of platform use for each portion of the forum corresponding to the inquiry phase within each section of the checklist

Inquiry Phase	Discussion (%)	Journal (%)	Data (%)	Summary (%)	Additional (%)
Immersion	38.2	16.0	0.0	4.2	6.1
Research Question	33.8	13.4	0.4	44.5	8.8
Prediction	37.6	14.3	0.6	51.0	8.6
Experimental Design and Procedures	45.6	6.6	0.4	18.8	6.5
Observations	16.9	10.8	11.8	3.9	8.7
Analysis and Results	30.3	15.4	0.6	26.3	7.3
Conclusions and Explanations	17.7	2.9	0.5	4.3	3.6
Future Research and Implications	14.1	2.9	0.0	4.3	3.6

To calculate the above percentages, the average number and percentages of the checked boxes was taken for each of the sections. Weight of each element within a section was assumed to be equal when averaged.

Discussion

Posting Habits

Student-teams and scientist-mentors posted in the Discussion Thread more often than the other participants. Teachers and other students rarely posted and most likely had a minimal impact on the student-teams' online learning environments. According to Henri (1992) interaction is defined by a three-step process. This process involves communication of information, then a response to the information, followed by a replay to that first response; thus for interactivity to occur there should be a minimum of three posts per discussion. The student-teams posted 8.46 times and scientist-mentors posted 5.72 times which indicates that they were involved in an interactive mentored discussion.

Inquiry Cycle

Criticisms of Student-Scientist Partnerships (SSPs) include the lack of structure to support students' engagement in an inquiry cycle, immersion activities, and in the development of the research project (Moss, Koehler, & Rock, 2008). Though evidence for quality engagement in an inquiry cycle decreased in the latter half, the PS forum still enabled some student-teams to complete inquiry cycles (*Future Research and Implications*, 14.3%). Also, approximately one-third of student-teams provided evidence that they had engaged in *Immersion* activities. In contrast, SSPs typically support students in the *Observation* and *Analysis and Results* phases of the inquiry cycle and do little to encourage student engagement in the other phases of an inquiry cycle. There is also evidence that *PS* students were involved in the development of their own research projects. The *Research Question* phase of the inquiry cycled showed the second highest amount of evidence for student engagement (59.4%). This indicates that students were actively involved in contributing to and developing their research questions. Over half of the student-teams provided evidence that they chose their research questions (51.3%). Student-teams also engaged in the *Experimental Design and Procedures* phase, where 62.0% developed an experimental design that enabled them to answer their own research questions and 42.4% provided evidence that they had developed their own experimental design.

Student-teams who provided the greatest amount of evidence for engagement in an inquiry cycle showed even more deviation from the inquiry cycle emphases of traditional SSPs. Almost 90% of the student-teams provided evidence that they engaged in the *Immersion* phase, over 90% provided quality evidence of engagement in the *Research Questions* phase, and 69.0% in the *Conclusions and Explanations* Phases. Almost all of the student-teams provided evidence that they developed their own research questions (88.9%) and research methods (92.6%).

When student-teams use *PS*, they are involved in an interactive mentored relationship with a scientist. While using PS, opportunities exist for students-teams to collaborate not only with their scientist-mentor but also with teachers and other students. However, the role of the teacher and other students was minimal. While, collaboration between students and scientist-mentors occurred most frequently, this type of collaboration occurred most often in the first parts of the inquiry cycle.

Though student-teams' overall results indicated an incomplete engagement in the inquiry cycle, performance in the *PS* online environment is similar to previous innovative and authentic approaches to inquiry-based learning in face-to-face settings. Krajcik et al. (1998) found that middle school students planned and designed thoughtful investigations but they did not focus on the scientific merit of their research questions. Students analyses, also, were weak and they failed to draw conclusions. The results of this study corroborated other researchers' findings, indicating that successful methods for guiding students through a complete authentic inquiry cycle have not yet been developed.

Use of the PS Platform Forums

Participants used all sections of each student-teams' forum. Evidence for quality inquiry engagement was found predominantly in the Discussion Thread and Summary sections. The Data section was used primarily for posting evidence of observations. Both the Journal and Additional sections contained evidence, but students did not use them as often to post quality evidence of engagement. These results were not unexpected because the Discussion Thread is shared by all types of participants, whereas three of the other sections (i.e., Journal, Data, Summary) were used exclusively by the students. While both the student-team members and the scientist-mentor could post in the Additional section, this section, along with the Data section , were the most underutilized. The Summary section was the second most used. The scaffolding for the student-teams in this section was straightforward. Student-teams were asked to post their research questions, research predictions, experimental design, and research conclusions to this section. The percentages corresponding to the inquiry phases, which align with the headings of the Summary section, were higher than the phases that did not, with the exception of the research conclusions.

Summary and Implications

Student-teams were more likely to provide evidence for quality engagement in the earlier phases of an inquiry cycle. The results of this study corroborate other researchers' findings, indicating that successful methods for guiding students through a complete authentic inquiry cycle have not yet been developed. Findings from this study suggest that more explicit attention needs to occur for these different phases of the inquiry cycle (Schwartz, Lederman, & Crawford, 2004). Along with classroom teachers, the scientist-mentors are in a position where they can emphasize parts of an inquiry cycle that typically receive less instruction and potentially motivate students to complete an inquiry cycle. PS is an online platform that enables students and scientist-mentors to engage in interactive and collaborative discourse. Perhaps scientist-mentors can use this discourse to further motivate students. Methods for sustaining the online collaboration throughout all parts of an inquiry might include providing examples of discourse between the students and the scientist-mentors to the workshop teachers and the scientist-mentors. I suggest the use of The Online Elements of Inquiry Checklist and its User Guide as a means of explicit support and a reflection. The OEIC can provide scaffolding to the scientist-mentors and teachers when they discuss and collaborate with students during the inquiry process.

PS provides an alternative to traditional SSPs. Collaboration between student-teams and scientist-mentors while they use the PS online platform can enable student-teams to more fully experience the inquiry cycle and engage in the development of their own unique inquiry projects. In addition, students have the opportunity to study other students' inquiry engagement and, if they are participating at the same time, engage these other students in direct collaborative discourse. However, results of this study indicate that students rarely ever discuss other students' work. Student-teams should be encouraged by their teachers and scientist-mentors to study and communicate with other students.

Participants used all of the various sections of the PS forum to interact and post materials. Interactive mentored discourse and collaboration occurred in the Discussion Thread. Student-teams also used the Summary Section more frequently than the other sections. This section is heavily scaffolded by prompts that are displayed directly on the forum and that correspond to phases of the inquiry cycle. Scaffolding by both mentors and programming appears to enable student-teams to provide greater evidence for engagement in the inquiry cycle.

Though teachers rarely posted, all of them had access to their student-teams' PS forums. These forums can provide teachers with means to formatively and summatively assess their student-teams' outcomes. Student-teams are using the PS forum to interact with scientist-mentors and to post information such as research summaries, journals, data files, presentations, images, and audio/video files. Teachers have the opportunity to view their student-teams' research as it progresses (formative) along with the final research artifacts (summative). Instruments such as the OEIC provide a valid and reliable tool to enable them to assess the quality and completeness of their students' engagement with their research projects.

Implications to consider when designing a more supportive online learning environment, therefore, include explicitly promoting the use prior students' research, determining ways to scaffold student motivation to complete their inquiry cycles, providing scaffolding for the teachers and scientist-mentors, and further scaffolding the website. The *PlantingScience* website contains accessible records of prior student-teams' research, however, this research rarely used. Consulting, comparing, and expanding upon prior research are authentic science activities. When designing an online learning environment, these activities must be explicitly promoted and strongly encouraged. Scaffolding for teachers and scientist-mentors in regards to the inquiry cycle should be considered. Student-teams are not completing inquiry cycles. Tools, such as the OEIC and its guide, can address this lack of completion by providing a set of guidelines for assessing quality engagement in an inquiry cycle. These guidelines can serve as prompts for the teachers and scientist-mentors when they engage in inquiry discussions with their student-teams. The website can also be further scaffolded by adding prompts that explicitly ask students-teams to share their background knowledge and experiences along with providing further recommendations and implications of their studies. These recommendations if enacted can provide further support for student-teams engaging in authentic science online learning environments.

CHAPTER V

DOES TEACHER WORKSHOP ATTENDANCE MAKE A DIFFERENCE? COMPARING SCIENCE STUDENTS' INTERACTIONS IN AN ONLINE LEARNING ENVIRONMENT THAT PROMOTES THE DEVELOPMENT OF SCIENTIFIC PRACTICES AND PROFICIENCIES

Inquiry in the Classroom Learning Environment

What is inquiry?

Inquiry has been “one of the most confounding terms within science education” (Settlage, 2003, p. 34). Inquiry in the classroom has a myriad of meanings. These meanings change depending on the context (e.g. Aulls & Shore, 2008; Grandy & Duschl, 2007; NRC, 1996; NRC, 2000). Though inquiry is a term that is commonly accepted by science education researchers, the definition, appearance, and role of inquiry in the science classroom is widely debated (Abrams, Southerland, & Evans, 2008).

Inquiry has a rich and complex history in the education literature. John Dewey introduced the concept of inquiry in science teaching in the 1920’s. Dewey believed that science teaching placed too much emphasis on gathering information and did not place enough emphasis on science as a way of thinking (Bybee, 2000; NRC, 1996).

Another influential figure in shaping our understanding of inquiry, who was exploring classroom inquiry in the 1960’s was Joseph Schwab. He believed that teachers and curricular materials presented science in a way that was inconsistent with modern science. Schwab believed that students could explore scientific phenomena with their own research questions, rather than with questions being given to them by textbooks or their teachers, and that students could also construct their own explanations and arguments for what was occurring (Abrams et al., 2008; Bybee 2000; Schwab, 1966).

The National Research Council (NRC) has also been influential in regard to inquiry and its role in reforming science education (NRC, 1996, 2000, 2007, 2008). The NRC maintains a position that student participation in science is an important goal of science learning and is a way for students to learn science (Abrams et al., 2008). Through reform efforts of organizations such as the NRC, a shift has occurred in the goals of science learning and the roles of students and instructors in the science classroom. This shift allows students to have greater opportunities to engage in and explore scientific phenomena over extended periods of time and develop scientific process skills and habits of mind.

The National Science Education Standards also describe and integrate three main contexts for inquiry, and in addition, their perceptions of what inquiry is and the types of activities that students are involved in when engaging in inquiry are also discussed. The NRC (1996) describes inquiry as an activity with many different facets, which involves the exploratory process of studying the natural world, making discoveries and then testing these discoveries to develop a deeper understanding. Students engage in inquiry to learn the scientific way of knowing of the natural world around them and to develop the skills and habits of mind to conduct inquiries. In addition, when students engage in inquiry, they engage in activities that allow them to develop knowledge and understanding of scientific ideas and how scientists study the natural world. These activities include observing, asking questions, consulting books and other resources to see what is known, planning investigations, reviewing what is already known in light of experimental evidence, using tools to gather, analyze and interpret data, and proposing answers, explanations, and predictions" (NRC, 1996).

Authentic science inquiry

Since Dewey, pressure by educational reformers has increased to have science learning resemble authentic science practice. During more recent time periods, technology has become increasingly more complex and accessible to students. According to Chinn and Malhotra (2002), many inquiry tasks given to students are not authentic science inquiry and do not reflect the central attributes of authentic science reasoning. "Authentic science inquiry refers to the research that scientists actually carry out" (Chinn & Malhotra, 2002, p. 177). Edelson, on the other hand, presents a more reasonable position and believes that scientific practice can be successfully adapted to learning environments (1998). Chinn and Malhotra contend that scientific research is a complex activity that uses expensive equipment, is based in elaborate procedures and theories, requires highly specialized expertise, and requires advance data analysis and modeling techniques (2002). Chinn and Malhotra (2002) developed a systematic analysis of authentic science reasoning that is based in the psychology, sociology, philosophy and history of science. This analysis can help accomplish the goal of creating simple inquiry tasks that capture the basic components of scientific reasoning. Edelson (1998) makes a point that technology can be used to aid students in managing these complex activities and help to create inquiry tasks in the classroom that capture the essence of inquiry but are appropriate for students.

Authentic science, according to multiple scientists, can have different objectives such as providing an experience of phenomena and events, demonstrating different ideas, principles or theories, developing skills need for laboratory work, making measurements, determining a relationship, testing hypotheses, manipulating variables, collecting data, or just seeing what can happen. However, theoretical speculation is needed because it allows a person to know what to inquire about, how to do it, and how to interpret the data (Wong & Hodson, 2009).

The process of doing a scientific inquiry requires continuous monitoring and modification. Perfect experiments do not exist. While, the way that science is presented through publication is rigid and step by step, the reality of conducting an authentic inquiry is much more fluid. Scientific endeavors also require creativity and imagination at all stages of an investigation (Wong & Hodson, 2009).

Characteristics of authentic science inquiry. Edelson's research (1998) focused on Authentic Science Learning (ASL) and the incorporation of technology. He believed that the benefits of ASL include students becoming active students, scientific knowledge being acquired in a meaningful context, and students developing styles of inquiry and communication that can enable them to become lifelong students. Incorporating technology can aid in the achievement of these benefits. The characteristics of authentic science practices include attitudes, tools and techniques, and social interaction. Attitudes are divided into uncertainty and commitment. In an authentic learning environment, students must have the opportunity to ask questions that reflect this uncertainty and are meaningful so they remain committed. Tools and techniques in science have been developed over time and are shared through communication. These tools and techniques must be adapted to the classroom in a manner that is reflective of science. Science also includes the communication of results, concerns, and questions to other members of the community.

One of the criticisms of inquiry and other forms of science teaching and learning is that there has been a sharp distinction between scientific processes and content. The NRC (2007, 2008) argues that content and process is linked. When students engage in the process of doing science it strengthens their understanding about both the phenomena and the way that that the phenomena is investigated. As a result the NRC has developed four strands of scientific practices and proficiencies. These four strands encourage students to use, develop, and integrate their (1) knowledge and use of scientific explanations; (2) generate and evaluate scientific evidence and explanations; (3) understand the nature and development of scientific knowledge; and (4) productively participate in scientific practices and discourse (2007, 2008). The four strands are deeply intertwined and cannot be separated from each other.

The inquiry cycle. Dewey envisioned the process of doing inquiry as a series of steps. The steps allowed students to define the problem, make observations, test their ideas, and produce generalizations or predictions (Aulls & Shore, 2008). However, the step-by-step scientific method currently used in classrooms distracts students and instructors from productive inquiry. Students do not have to follow the scientific method to pursue authentic research questions and investigations (Tang, Coffey, Elby, & Levin, 2010).

Within the science classroom, "there is little appreciation of the reflexive nature of experimental design, little recognition that scientists frequently have to engage in revision and reorientation of the procedures in order to overcome initial shortcomings in design" (Hodson, 2009, p. 34). Inquiry is a cyclical and intertwining process. The inquiry cycle is never completely over, yet many of the very textbooks and other resources that are presented to students provide information that appears to be "set in stone." Science and scientific knowledge is tentative and changes based on the development of new information. The different stages of inquiry are also typically taught in a step-by-step fashion instead of a cyclical pattern though this is not reflective of authentic science.

Inquiry teaching can produce positive outcomes (Anderson, 2002) including cognitive achievement, process skills (Shymansky, Kyle, & Alport, 1983), scientific literacy, vocabulary knowledge, conceptual understanding, critical thinking, and attitudes towards science (Haury, 1993). In a synthesis paper, that examined 138 research articles produced during an eighteen-year time span, Minner, Levy and Century (2010), found that instruction within an inquiry cycle increased student content learning. Students who actively engaged in this inquiry cycle by reflecting about it and participating in the investigation process showed an increase in their conceptual learning. According to the authors these findings are consistent with constructive learning theories, which predict that active construction of knowledge through interaction in inquiry is necessary for understanding.

Scaffolding

Scaffolding enables students to achieve learning and engage in practices that they would otherwise be unable to do. Scaffolding can be provided by various types of participants and can also be embedded in technological tools and activities. One way to provide scaffolding is through communication with peers and other types of facilitators. Another way is through computer scaffolding, where the programming takes the place of a facilitator. Scaffolding had previously been used to support an individual learner, but now it being used to aid groups of students. A movement amongst those in the learning sciences currently exists that use scaffolding in far more complex settings, such as classroom environments (Davis & Miyake, 2004).

Collaboration as a Form of Scaffolding. Collaboration can promote active knowledge construction and develop students' socio-cognitive skills (Haythornthwaite, 2006). The role of the teacher within the collaboration can differ from an instructional role where the teacher takes on some of the duties (i.e., dividing the work into stages, helping to facilitate communication amongst team members, project management, and content selection) to one where the students have much more control (Aviv, Erlich, Ravid, & Geva, 2000). When students have more control over their own learning, collaborative learning can be student-centered. Additionally, students are the source of authority and knowledge regarding their assignment and direct a significant amount of the learning (Downing & Holtz, 2008). While students have control over learning, a teacher or facilitator still monitors and provides feedback to the students (Bermejo, 2005).

Collaboration is important in the science profession because it brings together individuals with compartmentalized knowledge bases (Sonnenwald, 2007). Collaboration can create a community of inquiry where learners are fully engaged in socially constructing meaningful and worthwhile knowledge (Garrison, 2005).

Cyberlearning

Cyberlearning is “learning that is mediated by networked computing and communications technologies” (Pea, Borgman, Abelson, et al., 2008, p. 10). This type of learning offers new learning and educational approaches that use networked computing and communication technologies. In addition, learning experiences can occur over time and space. The NSF Task Force on Cyberlearning (Pea et al., 2008) was concerned primarily with student learning *with* cyberinfrastructure instead of learning *about* cyberinfrastructure. The Task Force suggested that cyberlearning takes place in a networked world where learning can occur in a hybrid manner from a variety of sources including personal experiences, education, and collective sources.

Cyberlearning takes place in a networked world where learning is not limited to face-to-face interactions and textbooks. Asynchronous communication (AC) is one mechanism for allowing students, teachers, and scientist-mentors to engage in authentic scientific discourse and collaboration. Occurring at any time and any place there is Internet access, asynchronous communication is convenient for students and facilitators. A computer program stores messages so that other participants can conveniently read and respond to others' comments. In addition to working at any time and in any place, research involving AC provides evidence of advantages to both students and facilitators, such as the creating a permanent record of conversations and artifacts. These records can be easily accessed and promote transparency in student and teacher outcomes.

Outcomes

"Assessments should provide teachers and students with timely feedback about students' thinking, and these assessments should support teachers' efforts to improve instruction" (NRC, 2008, p. 151). According to the NRC (2000) formative assessments are important for general guidance and planning. This type of assessment can be used to meet specific learning experiences and goals. However, formative assessments are insufficient in documenting outcomes to questions such as: "What have the students learned? What evidence demonstrates that they are learning? How well are they learning it, and at what level of competence?" (NRC, 2000, p. 76). Summative assessments are needed to determine these types of outcomes.

While many teachers embrace technology and new teaching practices, they have difficulties when adopting these new technologies and assessing their students' in the new learning systems. Teachers face a steep learning curve. Research into assessing these new learning systems needs to occur along with professional development programs that support teachers as they learn about and engage their students in these new learning systems (Peters & Slotta, 2010).

Professional Development

Most teachers participate in some professional development (PD) each year. PD programs have the potential to support teachers as they engage in new learning systems, and there is a growing body of research focused reform-based PD and improved student outcomes (Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009). In a meta-analysis of 1,300 research studies and evaluation reports, Darling-Hammond et al. (2009) found that positive student outcomes were associated with the following PD that is: (a) sustained, (b) intensive, (c) focused on specific curriculum content, (d) collaborative, and (e) aligned with goals of the teachers' schools.

Though PD should be sustained and intensive (Garet, Porter, Desimone, Birman, & Yoon, 2001) most teachers do not engage in PD very often. Darling-Hammond et al. (2009) reported that most teachers (57%) receive less than 16 hours of PD related to the content they teach and only 23% of teachers receive more than 33 hours. In regard to inquiry-based instruction, teachers who received 80 or more hours of PD were significantly more likely to put given teaching strategies into practice than teachers who received less amounts of time (Darling-Hammond et al., 2009).

PD should also be focused on specific curriculum content. Teachers lack strong content-specific teaching skills (Garet et al., 2001). PD is more effective if it addresses the reality of teaching and learning the content rather than if PD teaches methods that are taken out of context or is abstract. Teachers are more likely to implement classroom practices that have been modeled in context (Darling-Hammond et al., 2009).

PD also needs to allow for the development of collaborative communities and align with the goals of the schools associated with the teachers. PD should promote the development of collaborative communities by encouraging teachers to observe and critique each others' instruction along with attending the same PD experiences. PD is typically more effective when it is part of the reform efforts of the entire school, rather than in individual and isolated classrooms. If teachers cannot reconcile their school practices with the strategies they learned at the PD experience, then the PD will have little effect (Darling-Hammond et al., 2009).

The Learning Environment of *PlantingScience* for Teachers

While teachers are embracing cybertechnologies and new teaching practices, many have difficulties when adopting these new technologies and assessing their students in the new learning environments. Teachers face a steep learning curve, as teacher preparation, such as PD, typically prepares teachers for traditional teacher-directed instruction (Wood, 2009). One of Edelson's (1998) recommendations for the creation of innovative learning systems addresses teacher preparation. Resources and technologies can be introduced to teachers during preparatory periods designed to familiarize them with non-traditional roles in the classroom and the resources, technologies, and activities that allow them to use inquiry-based actives such as the ones that *PlantingScience* (PS) offers. PS familiarizes teachers with an online platform for an innovative learning system by providing teachers with online resources and holding professional development workshops. Teachers who attend PS workshops engage in inquiry modules facilitated by the scientists who developed the modules; they have opportunities to engage in discussions regarding the modules and use of the PS platform. This type of PD can support teachers as they engage in these new learning systems. Research into assessing these new learning systems must occur integrated into professional development programs that support teachers as they learn about and engage their students in these new learning systems (Peters & Slotta, 2010).

The *PlantingScience* (PS) innovative learning system is an environment that integrates innovative design, authentic science inquiry, and collaboration within an asynchronous learning network. Little is known currently about this type of learning system and its impact on students' development of scientific practices and proficiencies as they engage in the mentored inquiry cycles supported by the PS platform.

All teachers who use PS receive preparation and support via online asynchronous communication moderated by personnel in the Botanical Society of America. They also have access to open-ended curriculum modules and resources that provide ideas for adapting scientific tools, techniques, and investigations to the science classroom learning environment along with basic instructions on facilitating online communication between students and scientists and guiding questions.

Some teachers have attended professional development (PD) workshops at Texas A&M University, College Station. Nine-day PD workshops were held during the summers in 2008, 2009, 2010, and 2011 supporting 16 teachers each summer. All teachers had to have their administrations support to attend the workshop. During the first five days of the workshop, teachers engaged in inquiry experiences led by scientists who were involved in the development of modules emphasized during the workshop.

Workshop teachers were immersed in plant inquiries as learners, while the scientists provided them with extensive plant content and familiarized them with interactive tools available on the PS platform. Workshop teachers also "shared strategies for using online and classroom discourse and science notebooks as they designed an implementation plan for their own students" (Hemingway et al., 2011, p. 1536). Finally, workshop teachers became familiar with the online platform through direct instruction and use of the platform throughout the summer workshop.

PS developers assumed that PD programs preparing teachers for using innovative learning systems were beneficial not only to teachers but also to these teachers' students. My research occurred along with the PS PD program supporting teachers as they learned about and engaged their students in the PS learning environment.

Research Questions and Hypotheses

Two different types of teachers participated in PS. One group of teachers attended summer professional development (PD) workshops at Texas A&M University; the other group of teachers did not. The purpose of this study is to compare students' development of science practices and proficiencies in classrooms led by teachers with and without summer workshop experience. Workshop teachers' extensive PS preparation should benefit their students; and I expected a more extensive engagement of these students in an inquiry cycle. This study used tests of statistical significance stating null hypotheses. These null hypotheses stated that there would be no differences between the postings and engagement of workshop and non-workshop teachers' students. Therefore, the null hypotheses, are:

1. There will be no differences in the number of online postings of students in workshop and non-workshop teachers' classrooms.
2. There will be no differences between workshop and non-workshop teachers' students in their engagement in the inquiry cycle.

Methods

Research Design

The purpose of this exploratory two-phase mixed methods design (Creswell & Plano-Clark, 2011) was to evaluate the differences in students' science practices and proficiencies between the teacher guidance of the PS learning environments. Evidence of students' science practices and proficiencies was expressed via engagement in an inquiry cycle while using the PS platform. This engagement was measured using an instrument called the Online Elements of Inquiry Checklist (OEIC; Peterson & Stuessy, 2011). During the first phase of this study (QUAN), selection parameters were determined and a sampling plan was designed and implemented. During the second phase (MIXED), cases were selected for analysis. Specifically, this analysis compared how student-teams engaged in inquiry online using the PS platform, depending on whether or not if their teachers attended a PS summer workshop. (See Figure 5.1.)

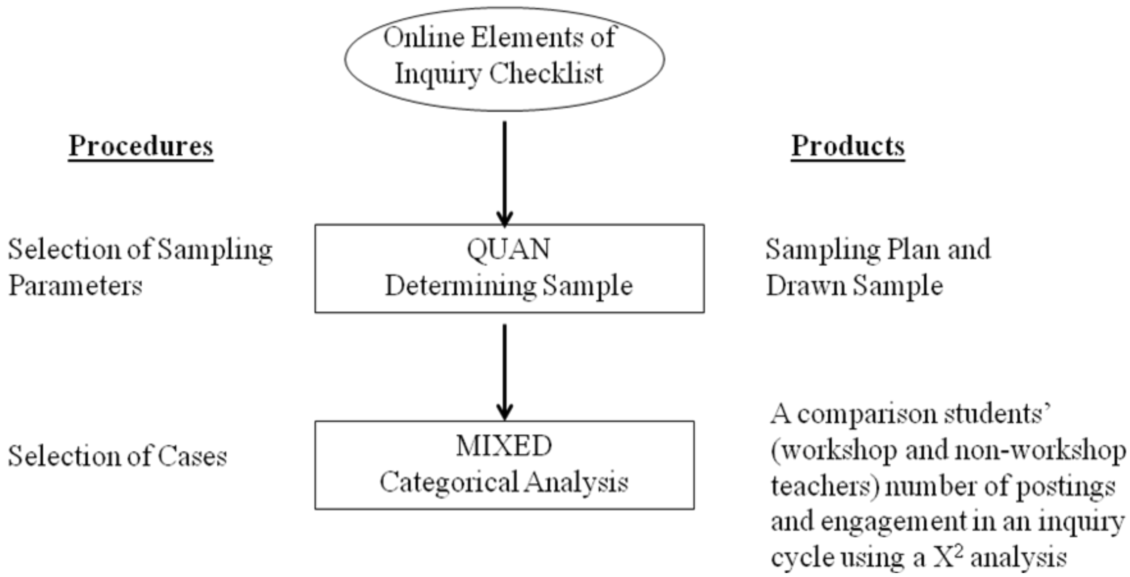


Figure 5.1. Visual model of the exploratory mixed methods study used to compare the use an online inquiry-based learning environment by students whose teachers either attended or did not attend a PS workshop. (Based on Creswell & Plano-Clark, 2011.)

Data Sources

The Botanical Society of America developed the PS database to archive participants' use of the PS platform. This database contains all the records of student-teams, scientist-mentors, and teachers who have participated in PS since 2005. Data included basic demographic information about teachers, scientist-mentors, and all other participants' use of the online PS platform forums. The database includes information about the student-teams, including their school name, completion of summary section, name of their teacher, type of module used, and number of posts. However, individual students' actual or full names are not accessible. Information stored about the scientists includes number of years as a mentor, their university, and their chosen field of inquiry. Teacher information includes number of years using PS, school name, and workshop attendance. Forums from the 263 sampled student-teams were used in the mixed methods analysis. The various posted materials and discourse between students, scientist-mentors, and teachers were used to explore and evaluate online engagement in an inquiry cycle.

Sampling Plan

As of 2011, over 900 scientist-mentors and 3,000 student-teams had used the PS platform to engage in plant-based inquiry projects. To assure that my investigations represent optimal yet scientifically accurate results in answering these questions, I developed a plan that allowed me to draw a proportionate and probabilistic sample of student-teams who used the PS platform.

During the first five years (2005-2009) of its existence, a total of 1,287 student teams (N_1) made use of the PS online platform. A sample of student-teams was used to describe and generalize the platforms' effectiveness. Prior to sampling, teams involved during beta testing of the platform's modules and /or those participating as university students were removed. Teams with university-level students were removed because this research focused only on secondary school level students. Student-teams who were beta-testing inquiry modules still in development were removed because there were too many unknown confounding variables that could be introduced into the research sample. The removal of these teams resulted in a true population of 824 student-teams (N_2). To achieve a 5% confidence interval during data analyses, a probability sample of 263 (n_2) student-teams were selected. Using a stratified sampling design, the true population of student-teams was stratified into six exhaustive and mutually exclusive sampling frames.

These frames were defined by semester (Fall 2008, Spring 2008, or Fall 2009) and module type, either *Wonder of Seeds* (*WoS*) or *Power of Sunlight* (*PoS*). Within each of these frames, student-teams were listed by student school level (middle or high

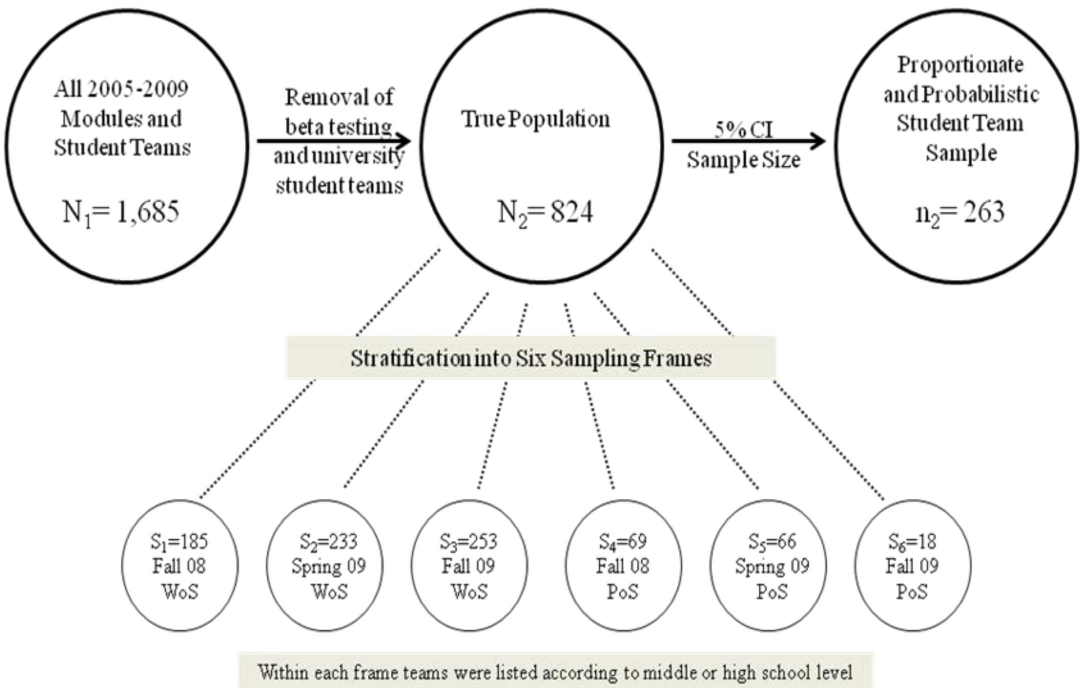


Figure 5.2. Design of sampling plan.

school). Finally, a proportionate and probabilistic sample of student-teams was selected from each of the six frames (See Figure 5.2 and Table 5.1). This sampling plan resulted in a sample of 59 *WoS* and 22 *PoS* student-teams from Fall of 2008, 74 *WoS* and 21 *PoS* student-teams from Spring of 2009, and 81 *WoS* and 6 *PoS* student-teams from Fall of 2009. (See Table 5.2.)

Table 5.1
Distribution of the true population of student-teams according to sample frame (N_2=824)

Module	Fall 08	Spring 09	Fall 09	Total
WoS	185	233	253	671
PoS	69	66	18	153
Total	254	299	271	824

Table 5.2
Distribution of the sample of student-teams according to sample frame (n_2=263)

Module	Fall 08	Spring 09	Fall 09	Total
WoS	59	74	81	214
PoS	22	21	6	49
Total	81	95	87	263

Of the 263 student teams sampled, 44 student teams had teachers who had attended a PS summer workshop. The remaining 219 student teams had teachers did not attend a summer workshop.

Instrument and Variables

The Online Elements of Inquiry Checklist (OEIC) (Peterson & Stuessy, 2011) was developed to measure participation within an inquiry cycle situated in an online learning environment. The OEIC, however, cannot measure face-to-face interactions in the classroom. The OEIC measures the frequency and quality of participants' online engagement within an inquiry cycle. The OEIC integrates literature sources such as the National Science Education Standards (NRC, 1996; 2007), Berland and Reiser (2009), Chinn and Malhotra (2002), Germann, Haskings, and Auls (1996), and Krajcik et al. (1998).

The OEIC is divided into nine sections: (a) *Summary Table*, (b) *Immersion or Setting the Stage*, (c) *Research Question*, (d) *Prediction*, (e) *Experimental Design and Procedures*, (f) *Observations*, (g) *Analysis and Results*, (h) *Conclusions and Explanations*, and (i) *Future Research and Implications of the Study*. The number of postings by each type of participant and which sections of the forum are used is recorded in the *Summary Table*. The remaining sections represent the eight phases of an inquiry cycle (Peterson & Stuessy, 2011). Each of these sections is divided into various inquiry elements. The OEIC evaluates the role of the students, scientists, students from other teams and schools, and teachers as they communicate using the various online posting options provided by the platform within each student-teams forum. These online posting options include discussion threads, journals, summaries, and uploaded documents. See Appendix B for an example of the complete instrument.

Accompanying the OEIC is the *OEIC Guide*. This guide explains the purpose for the OEIC, describes the main categories of the OEIC, and discusses the limitations of the OEIC. In addition, each inquiry element from the checklist is operationally defined and supported by authentic examples from the PS website. See Appendix C for the *OEIC guide*.

A team of six experts in the natural and social sciences were recruited to develop and refine the OEIC. Additionally, three PS scientist-mentors were involved in the inter-rater reliability assessment of the OEIC. An inter-rater reliability coefficient of 91.9%

was established for the OEIC by the three scientist-mentors. A split half analysis was used to determine the degree of internal consistency between two halves of the tested results (Tashakkori & Teddlie, 1998). The Spearman-Brown Coefficient (r) was .96, indicating a high level of internal consistency for the OEIC.

Data Analysis

Hypothesis 1. The first hypothesis is that there would not be a difference in the number of online postings of students in workshop and non-workshop teachers' classrooms. To determine the posting habits of the student-teams and to compare these habits between workshop and non-workshop teachers' student teams', frequency tables were created and modal values, means, etc. were calculated. In addition, a standard frequency distribution analysis was used to describe students' use of the forum. A Chi-Square Test of Independence was used compare the posting habits of students representing the two teacher groups. My null hypothesis is that the number of students' postings will not differ.

Hypothesis 2. The second hypothesis was that there would be no differences between workshop and non-workshop teachers' student in their engagement in the inquiry cycle. To assess differences in students' (workshop and non-workshop teachers) engagement in an inquiry cycle while using PS, 40 hypotheses corresponding to each element of inquiry were generated to test the quantity and quality of students' engagement in the inquiry cycle. Student engagement in each inquiry element was tested. My null hypothesis is that for each element no difference will exist between each type of students' engagement in that particular element.

To determine student-team engagement in an inquiry cycle and to compare this engagement between the student-teams of workshop and non-workshop teachers', frequency tables were created and a frequency distribution analysis was performed. In addition, a standard frequency distribution analysis was also used to describe student-teams' use of the forum. A Chi-Square Test of Independence was used compare inquiry cycle engagement between the two different groups of students.

Findings

Hypothesis 1. There will be no differences in the number of online postings of students in workshop and non-workshop teachers' classrooms.

Student-teams participating in the *PlantingScience* online platform on average posted 8.57 times, with a minimum of zero and maximum of 44 posts, if their teachers attended the workshop. Of these 44 student-teams, one team did not post. If the teachers did not attend the workshop, the student-teams posted an average of 8.44 times with a range of 0-38. Seven of the 219 student-teams did not post. (See Table 5.3.) No significant difference was found between the student-teams in regard to the number of their posts [χ^2 (3, N=263) = 2.570, p = 0.463], and the null hypothesis was accepted.

I first created a frequency table to determine the overall distribution of the number of posts. Next, quartiles were created so that 25% of the student teams fell within each quartile. As a result, student-teams with 0-4 posts were assigned to the first quartile, student-teams with 5-7 posts were assigned to the second quartile, student-teams with 8-11 posts to the third quartile, and student-teams with 12 or more posts to the final quartile. Workshop and non-workshop teachers' student-teams were then compared to each other according to the number of their posts. Quartiles were used, as comparing the two groups of students-teams directly would have created empty cells. Empty cells violate one of assumptions of a Chi-Square Test of Independence.

Table 5.3
Student-teams (n=263) number of posts according to teachers' workshop attendance

Number of Posts	Workshop Teacher n=44	Non-Workshop Teacher n=219
Mean	8.57	8.44
Minimum	0	0
Maximum	44	38

Workshop and non-workshop teachers' student-teams showed no significant difference in their journaling habits [χ^2 (1, N=263) = 0.172, p = 0.678]. Other areas of posting habits, however, revealed differences and the null hypotheses were rejected three times. Student-teams whose teachers attended the workshop were more likely to upload Student Data Files [χ^2 (1, N=263) = 4.344, p = 0.037] and additional types of files such as final presentations, images, audio, and video [χ^2 (1, N=263) = 3.905, p = 0.048]. However, the workshop teachers' student-teams were less likely than the non-workshop teachers' student-teams to have posted in the summary section [χ^2 (1, N=263) = 5.186, p = -0.140]. The effect sizes for these posting habits however, were relatively small. (See Table 5.4.)

Table 5.4

Comparison of the posting habits of workshop and non-workshop teachers' student-teams (n=263)

Posting Habit	χ^2	Effect Size[a]
Number of Posts	2.570	0.463
Journaling	0.172	0.678
Data Files	4.344*	0.129
Summaries	5.186*	-0.140
Additional	3.905*	0.122

Chi-square values compare proportions of evidence provided for each element of inquiry by workshop (n=44) and non-workshop (n=219) teachers' students. (*df*=1)

[a]Effect sizes reported are phi. Negative values indicate that student-teams of workshop teachers provided less evidence than those of non-workshop teachers.

*p<0.05.

**p<0.01.

***p<0.001.

Student-teams had the option of posting several different types of additional resources: presentation files, images, and audio/video files. No significant differences were found in the posting habits of the workshop and non-workshop teachers' student-teams in regards to whether or not the student-teams were posting images [χ^2 (1, N=263) = 3.581, p = 0.058] and/or audio/video files [χ^2 (1, N=263) = 0.199, p = 0.655]. Thus, the null hypothesis for the posting habits of student-teams in regard to audio/video files and uploaded images was accepted. However, the null hypothesis was rejected for student-teams uploading presentation files. Student-teams' whose teachers attended the workshop were more likely to upload presentation files than students whose teachers did not attend the workshop [χ^2 (1, N=263) = 4.152, p = 0.042].

Hypothesis 2. There will be no differences between workshop and non-workshop teachers' students in their engagement in the inquiry cycle.

Each of the eight phases of the inquiry cycle has between two to eight elements of inquiry. A total of 40 null hypotheses were tested, one for each element of inquiry. Each null hypothesis stated that there would be no difference between workshop and non-workshop teacher students' evidence of engagement with a particular element of inquiry.

Immersion or Setting the Stage. Less than 40% of all students provided evidence for engagement within immersion. 38.6% (n=91) students mentioned information-gathering efforts and they seldom mentioned prior knowledge or experiences that enabled them to question the relationships between variables that they were planning to investigate (30.4%, n=80). (See Table 5.5.)

Table 5.5
Student-teams (n=263) providing evidence of engagement in the elements for Immersion or Setting the Stage

Element of Inquiry	Frequency	Percent
Students mentioned information-gathering efforts.	91	38.6
Students mentioned prior knowledge or experiences that enabled them to question the relationships between variables.	80	30.4

Within the Immersion Phase, a significant difference between workshop and non-workshop teachers' student teams was found and the null hypothesis was rejected for one of the two elements of inquiry. Student-teams whose teachers attended the workshop were more likely to mention information gathering efforts [χ^2 (1, N=263) = 5.537, p = 0.019].

Research Questions. Most of the student-teams provided research questions appropriate for the context of the research (85.9%, n=226) and discussed variables that were observable and/or measurable (73.7%, n=194). Many student-teams linked their research question to a prediction (58.9%, n=155), provided a testable causal-based research question (63.9%, n=168), and provided a causal-based research question where the variables were the focus (63.9%, n=168). However, approximately, half of the student-teams provided evidence that they chose their own research questions (51.3%, n=135) and provided a research question that could be answered within the scope and boundaries of the inquiry setting (43.3%, n=114). Student-teams seldom provided explicit evidence that their research questions were tied to prior knowledge or experience (33.8%, n=80). (See Table 5.6.)

Of the eight elements of inquiry within the Research Questions Phase of the inquiry cycle, significant differences in the online engagement between workshop and non-workshop teachers' student-teams were observed for two of the elements and these null hypotheses were rejected. Student-teams whose teachers attended the workshop were more likely to provide a research question that could be answered within the scope and boundaries of the inquiry setting [χ^2 (1, N=263) = 6.985, p = 0.008]. However, the student-teams whose teachers attended the workshop were less likely to provide a causal based research question where the variables were the focus [χ^2 (1, N=263) = 4.411, p = 0.036].

Table 5.6
Student-teams (n=263) providing evidence of engagement in the elements for Research Questions

Element of Inquiry	Frequency	Percent
Students provided a research question that was appropriate for the context of the study.	226	85.9
Students discussed variables of interest that were observable and/or measurable.	194	73.7
Students provided explicit evidence that the research question is tied to prior knowledge or experience.	89	33.8
Students provided evidence that they chose their own research questions.	135	51.3
Students provided a research question that could be answered within the scope and boundaries of the inquiry setting.	114	43.3
Students logically linked their research question to a prediction, hypothesis, or expectation.	155	58.9
Students, if the question was causal in nature, provided a research question that was **testable** through a scientific investigation.	168	63.9
Students, if the question was causal in nature, provided a research question where the relationship between the variables was the focus.	168	63.9

Prediction. Almost all of the student-teams provided evidence that they considered possible outcomes of their investigations (92.8%, n=244). However, student-teams seldom provided evidence that their project outcomes were based on prior knowledge or experience (35.3%, n=93). Many student-teams provided a predicted outcome that was reasonable in light of the research question being asked (64.3%, n=169). (See Table 5.7.)

Table 5.7
Student-teams (n=263) providing evidence of engagement in the elements for Prediction

Element of Inquiry	Frequency	Percent
Students considered possible or probable outcomes to their investigation.	244	92.8
Students provided evidence that a projected outcome was based on prior knowledge or experience.	93	35.3
Students provided a predicted outcome that was reasonable in light of the research question that is being asked.	169	64.3

There was one element of inquiry where workshop and non-workshop significantly differed in their evidence of engagement for the *Prediction* phase of an inquiry cycle and the null hypothesis was rejected. Student-teams whose teachers attended the workshop were less likely to provide a predicted outcome that was reasonable in light of the research question that was being asked [χ^2 (1, N=263) = 4.677, p = 0.031].

Experimental Design and Procedures. Many of the student-teams provided evidence of a research design that could enable them to answer their research question (61.9%, n=163). Less than half of the student-teams provided evidence that they developed their own research methods (42.2%, n=111) and mentioned controls of variables (44.1%, n=116). Student-teams seldom provided a description of research methods that provided enough detail for replication (28.9%, n=76) or mentioned confounding variables (44.1%, n=116). Student-teams rarely controlled for possible sources of error in their observations (6.8%, n=18). (See Table 5.8.)

Table 5.8
Student-teams (n=263) providing evidence of engagement in the elements for Experimental Design and Procedures

Element of Inquiry	Frequency	Percent
Students provided a research design that enabled them to answer their research question.	163	61.9
Students provided evidence that they developed research methods.	111	42.2
Students provided a description of research methods that was in enough detail so that another research group could replicate them.	76	28.9
Students mentioned confounding variables.	57	21.7
Students mentioned controls of variables.	116	44.1
Students controlled for possible sources of error in their observation methods.	18	6.8

The null hypothesis was rejected twice during the *Experimental Design and Procedures* phase, with significant differences for two of the six elements of inquiry. 70.5% of the workshop teachers' student-teams provided evidence that they developed research methods; in comparison only 36.5% of the non-workshop teachers' student-teams did so [χ^2 (1, N=263) = 17.287, p = 0.000]. Also, 54.4% of workshop teachers' student-teams mentioned confounding variables; as compared with 15.1% of non-workshop teachers' student-teams [χ^2 (1, N=263) = 33.636, p = 0.000].

Observations

Many of the student-teams recorded research events (72.2%, n=190) and described what they observed (57.0%, n=150). Some of the student-teams included data tables (29.7%, n=78), provided visual displays of their data (35.4%, n=93) and provided visual displays following accepted conventions (17.9%, n=47). Student-teams rarely described or discussed their data tables or visual displays (9.1%, n=24). (See Table 5.9.)

Table 5.9
Student-teams (n=263) providing evidence of engagement in the elements for Observation

Element of Inquiry	Frequency	Percent
Students recorded research events.	190	72.2
Students described what they observed.	150	57.0
Students included data table(s).	78	29.7
Students described or discussed the data table(s).	24	9.1
Students provided visual displays of their data such as graphs, charts, or pictures.	93	35.4
Students described or discussed the visual displays.	24	9.1
Students provided visual displays which follow accepted conventions (labels, legends, units of measure, accurate format).	47	17.9

Significant differences occurred between workshop and non-workshop teacher's student-teams in four of the seven inquiry elements for the *Observation* phase of an inquiry cycle (null hypothesis was therefore rejected four times). Student-teams whose teachers attended a workshop were more likely to record research events [χ^2 (1, N=263) = 7.081, p = 0.008], describe what they observed [χ^2 (1, N=263) = 5.310, p = 0.021] and include data tables [χ^2 (1, N=263) = 4.633, p = 0.031].

Analysis and Results. Most of the student-teams mentioned patterns or trends in their data (78.7%, n=207). Approximately half of the student-teams mentioned unexpected results (47.9%, n=126) and used data to answer their research question

(50.6%, n=133). Student-teams rarely compared data across multiple studies from other student-team groups (1.5%, n=4). (See Table 5.10.)

Table 5.10
Student-teams (n=263) providing evidence of engagement in the elements for Analysis and Results

Element of Inquiry	Frequency	Percent
Students mentioned patterns or trends in the data.	207	78.7
Students compared data across multiple studies from other student groups.	4	1.5
Students mentioned unexpected results.	126	47.9
Students used data to answer the research question.	133	50.6

No significant differences occurred between the evidence of engagement in *Analysis and Results* provided by workshop and non-workshop teachers' student-teams. All null hypotheses for this phase were accepted.

Conclusions and Explanations. Approximately half of the student-teams connected their conclusions of the experiment to the data that they collected (52.1%, n=137) and provided conclusions consistent with the data that was collected (43.0%, n=113). Student-teams seldom supported ideas about causality with data (25.9%, n=68), mentioned alternative results (18.3%, n=48), mentioned alternative explanations (18.3%, n=48), and justified their conclusions using their data (14.8%, n=39). Student-teams, rarely, compared their results to other studies' results (2.7%, n=7), discussed the limitations of their research (14.8%, n=39), and provided evidence of an expressed model or knowledge claim that explained relationships among variables with the natural phenomenon which was under investigation (13.7%, n=36). (See Table 5.11.)

Significant differences occurred between workshop and non-workshop teachers' student-teams for two of the eight elements of inquiry for the *Conclusion and Explanations* phase (null hypothesis rejected twice). Student-teams whose teachers attended the workshop were more likely to connect their conclusion of the experiment to the data that was collected [χ^2 (1, N=263) = 9.016, p = 0.003]. Workshop teachers' student-teams were also more likely to have conclusions which were consistent with the data that was collected [χ^2 (1, N=263) = 9.213, p = 0.002]

Table 5.11
Student-teams (n=263) providing evidence of engagement in the elements for Conclusions and Explanations

Element of Inquiry	Frequency	Percent
Students connected their conclusions of the experiment to the data that was collected.	137	52.1
Students had conclusions which were consistent with the data that was collected.	113	43.0
Students supported ideas about causality with data.	68	25.9
Students mentioned alternative explanations.	48	18.3
Students compared their results to other studies' results.	7	2.7
Students discussed the limitations of their research.	39	14.8
Students justified their conclusions using data.	64	24.3
Students provided evidence of an expressed model or knowledge claim that explained relationships among variables with the natural phenomenon which was under investigation.	36	13.7

Future Research and Implications. Student-teams rarely discussed the implications of their study (5.7%, n=15) or mentioned possible study revisions (22.8%, n=60). Nor were there any significant differences in the evidence of engagement provided by the workshop and non-workshop teachers' student-teams. The null hypothesis was accepted twice. (See Table 5.12.)

Table 5.12
Student-teams (n=263) providing evidence of engagement in the elements for Future Research and Implications

Element of Inquiry	Frequency	Percent
Students discussed the implications of their study.	15	5.7
Students mentioned possible study revisions.	60	22.8

Effect Size. The phi coefficient, a non-parametric measure of association, was used to estimate the effect size for each of the elements of inquiry where there were significant differences in the evidence of engagement provided by workshop and non-workshop teachers' student-teams. Phi varies between -1 and 1. If it is close to 0, the value indicates little association between variables; conversely the closer phi is to 1 or -1 the stronger the association. Typically, values of .20 and above or -.20 and below are considered moderate. A phi value below .20 and above -.20 is considered small. Two of the elements, student-teams providing evidence that they had developed their own research methods and that they had mentioned confounding variables, had moderate effect sizes. They were both found in the *Experimental Design and Procedures* phase of the inquiry cycle. Another group of elements to consider, which had effect sizes approaching .20, were found in the *Conclusions and Explanations* phase of the inquiry cycle. (See Table 5.13.)

Table 5.13
Comparison of evidence provided for each element of inquiry for which there was a significant difference between workshop and non-workshop teachers' student-teams

Phase	Element of Inquiry	χ^2	Effect Size[a]
Immersion	Students mentioned information-gathering efforts.	5.537*	0.145
Research Question	Students provided a research question that could be answered within the scope and boundaries of the inquiry setting.	6.985**	0.163
	Students, if the question was causal in nature, provided a research question where the relationship between the variables was the focus.	4.411*	-0.130
Predictions	Students provided a predicted outcome that was reasonable in light of the research question that is being asked.	4.677*	-0.133
Experimental Design and Procedures	Students provided evidence that they developed research methods.	17.287***	0.256
	Students mentioned confounding variables.	33.636***	0.358
Observations	Students recorded research events.	7.081**	0.164
	Students described what they observed.	5.310*	0.142
	Students included data table(s).	4.633*	0.133
	Students provided visual displays of their data such as graphs, charts, or pictures.	6.823**	-0.161
	Students provided visual displays which follow accepted conventions (labels, legends, units of measure, accurate format).	4.398*	-0.129
Conclusions and Explanations	Students connected their conclusions of the experiment to the data that was collected.	9.016**	0.185
	Students had conclusions which were consistent with the data that was collected.	9.213**	0.187

Chi-square values compare proportions of evidence provided for each element of inquiry by workshop (n=44) and non-workshop (n=219) teachers' students. (*df*=1)
[a]Effect sizes reported are phi. Negative values indicate that student-teams of workshop teachers provided less evidence than those of non-workshop teachers.
*$p<0.05$.
**$p<0.01$.
***$p<0.001$.

Discussion

Student Posting Habits

According to Henri (1992) interaction is defined by a three-step process. This process involves communication of information, then a response to the information, followed by a replay to that first response; thus for interactivity to occur there should be a minimum of three posts per discussion. The student-teams posted an average of 8.5 times indicating involvement in interactive discussions. The PS session within each classroom ranged from one to eight weeks depending on the teachers' allocation of time for PS. Workshop and non-workshop teachers' student-teams showed no significant difference in the number of their posts, though the overall workshop teachers' students provided more evidence of engagement in an inquiry cycle. This trend indicates that posts of the workshop teachers' students were of higher quality than that of the non-workshop teachers' students.

While there were no differences in the number of posts between types of student-team, there were differences in how the student-teams used the platforms. Workshop teachers' student-teams were more likely to post presentation and data files, whereas, they were less likely to fill out the summary section. Workshop teachers' students were more likely to post evidence of their observations in their presentation and data files.

Student-Team Engagement in the Inquiry Cycle

Though evidence for quality engagement in an inquiry cycle decreased in the latter half of the cycle, the PS forum still enabled some student-teams to complete inquiry cycles as evidenced by student participation in *Future Research and*

Implications. Student-teams' overall results indicated an incomplete engagement in the inquiry cycle, performance in the *PS* online environment is similar to previous innovative and authentic approaches to inquiry-based learning in face-to-face settings. Krajcik et al. (1998) found that middle school students planned and designed thoughtful investigations, but they did not focus on the scientific merit of their research questions. Students' analyses, also, were weak and they failed to draw conclusions. The results of a portion of this study, which use all of the student-teams grouped together, corroborated other researchers' findings, indicating that successful methods for guiding students through a complete authentic inquiry cycle have not yet been developed. However, there appears to be a positive association between workshop teacher attendance and evidence for quality student engagement.

Each element of inquiry for the eight phases of an inquiry cycle had null hypotheses stating that no differences in the evidence for engagement provided by workshop and non-workshop teachers' students. Of the forty null hypotheses, 13 were rejected and alternative hypotheses were accepted. Workshop teachers' students were more likely to provide evidence for engagement in nine elements of inquiry. These elements of inquiry were scattered throughout five of eight inquiry phases beginning with *Immersion and Setting the Stage* and ending with *Conclusions and Explanations*.

Students whose teachers attended the workshop were more likely to mention information-gathering efforts, provide a research question that could be answered within the scope and boundaries of the inquiry setting, take control of their experimental design and procedures by developing their own research methods, mention confounding variables, record research events, describe what they observe, and provide data tables. In addition, these students were also more likely to connect their conclusion of the experiment to the data that was collected and have conclusions which were consistent with the data that was collected. These results indicate that students' whose teachers attended the workshop were more likely to engage in a more complete inquiry cycle.

During the summer PD workshops, teachers were involved in a prolonged period of inquiry engagement, while reform based teaching strategies were modeled by scientists. These scientists engaged the teachers in lengthy periods of immersion and discussion about these experiences. Workshop teacher's students were more likely to mention information gathering efforts. The scientists also encouraged the teachers to ask various research questions and allowed the teachers time for reflection and revision of their research questions before conducting their investigations. During this process of research question generation, reflection, and revision, the scientists and teachers engaged in prolonged discussions regarding potential research questions. During the workshops, teachers were encouraged to ask both causal research questions and descriptive research questions. Students of workshop teachers were more likely to provide research questions appropriate for the research setting. In addition, non-workshop teachers' students were less likely to ask descriptive research questions and more likely to ask causal research questions. These results mirror the teachers' workshop experiences where they provided different types of research questions and engaged in immersion activities.

During the workshops, teachers received extensive instruction on how to design their experimental design and procedures. Teachers were given ample opportunities to design and revise their experiments. The scientists and teachers discussed the various variables that could be explored through various means along with confounding variables that could impact the investigation. Students whose teachers attended the workshop were much more likely than non-workshop teachers' students to provide evidence that they had developed their own research methods and to mention confounding variables.

During the workshops, teachers were asked to record and describe all of the observations that they made during the inquiry process and to post these observations daily online in their PS forums. During the workshop, especially in 2008, there was an emphasis on creating data tables by hand and in spreadsheets. Workshop teachers' students were more likely to record and describe their observations than non-workshop teachers' students. In addition, the workshop teachers' students were also more likely to provide data tables. Non-workshop teachers' students, however, were more likely to provide visual displays of their data such as graphs, charts, or pictures and to have these visual displays follow accepted conventions.

During the workshops, the scientists discussed conclusions and explanations with the workshop teachers. Often times, the scientists would ask the teachers to connect their explanations with the evidence that they had collected. The scientists would ask the teachers what they were thinking, why they were thinking that, and what did "that" have to do with the evidence that they collected. Students whose teachers attended the workshop were more likely to connect their conclusions to the data that they collected and to present conclusions that were consistent with the data that they collected.

Summary and Implications

The *PlantingScience* (PS) innovative learning system is an environment that integrates innovative design, authentic science inquiry, and collaboration within an asynchronous learning network. Little is known currently about this type of learning system and its impact on students' development of scientific practices and proficiencies as they engage in the mentored inquiry cycles supported by the PS online platform. Findings from this study suggest that while students have the opportunity to engage fully in inquiry cycles online, they are not doing so. However, students whose teachers attended the summer professional development (PD) workshop were more likely to post evidence of quality engagement in an inquiry cycle, even though the number of posts did not differ. Differences between workshop and non-workshop teachers' students were represented in 14 different inquiry elements dispersed throughout the inquiry cycle. Students whose teachers attended the workshop were more likely to engage in nine of these different inquiry elements. These elements were spread throughout the inquiry cycle. These results indicate that there is an association between workshop attendance and positive student inquiry outcomes.

Characteristics of teacher professional develop (PD) that can lead to positive student outcomes include the following attributes. PD is: (a) sustained, (b) intensive, (c) focused on specific curriculum content, (d) collaborative, and (e) is aligned with goals of the teachers' schools. During the nine-day summer PD experiences, workshop teachers had the opportunity to engage in complete inquiry cycles while being immersed in two to three different *PlantingScience* (PS) modules (number of modules depended on the session attended). These inquiry modules were facilitated and modeled by the scientists who were involved in their development. Teachers then engaged in discussions regarding the implementation of PS in their classrooms and the use of online PS platform. The PD offered by the PS summer workshop was prolonged and focused on specific curriculum content.

Though PS cannot promote collaborative communities at each of the teachers' schools, PS does promote collaborative communities that extended past the walls of the classrooms. Teachers who use PS receive preparation, support, and opportunities to collaborate via online asynchronous communication moderated by personnel in the Botanical Society of America (BSA). In addition, to the personnel at BSA, teachers can collaborate online with each other and scientists mentors. PS also provides opportunities for teachers to share their student outcomes at regional and national professional meetings. PS also cannot align with the goals of each school; however, each teacher was required to have their administrators support to attend the workshop. Also, the plant biology and inquiry aspects of PS align with national science education standards.

This study shows a positive association between teacher workshop attendance and student scientific practices and proficiencies. Therefore, it is recommended that PS should continue to provide PD experiences. However, additional emphasis should be placed on student engagement in a complete inquiry cycle. Parts of the inquiry cycle where the evidence of engagement was underrepresented, such as *Future Research and Implications*, should be explicitly addressed during these workshops.

CHAPTER VI

CONCLUSIONS

PlantingScience (PS) is a unique web-based learning system in which students develop scientific practices and proficiencies as they engage in hands-on classroom investigations while being mentored by a scientist. In the past, PS teachers have had the opportunity to attend quality professional development (PD) experiences. During the PD, teachers engaged in hands-on investigations that were facilitated by a scientist and had opportunities to discuss issues related reform-based teaching and learning. In addition, PS uses an online web-based platform where scaffolding is provided via programming and through discourse with others. The overarching goals of my dissertation were to first develop a process for assessing student learning outcomes associated with their use of this unique learning system and second, to evaluate inquiry engagement within this system.

The purpose of Chapter III was to describe the development of a valid and reliable instrument measuring participants' (i.e., students, scientist-mentors, and teachers) engagement in an inquiry cycle promoting students' scientific practices and proficiencies. To develop this instrument, I first had to identify the phases of an inquiry cycle and determine the elements (a measure of quality engagement) that comprised each phase. Using a recursive and iterative process, I integrated the information found in the literature sources with inquiry cycle examples from the PS website. Next I collaborated with a group of practitioner experts to further refine the instrument and establish its construct and content validities. The instrument, entitled the Online Elements of Inquiry Checklist (OEIC), was then used by scientists and its Inter-Rater Reliability was established. In addition, the OEIC's internal measure of reliability was determined by conducting a Spilt Half analysis. This development process resulted in a valid and reliable instrument capable of measuring participants' engagement in an inquiry cycle while using the PS online platform. The OEIC was used in the studies discussed in Chapters IV and V.

Chapter IV describes the process and results of a study where I explored and evaluated the engagement of students, scientist-mentors, and teachers in an inquiry cycle while using the PS online platform. During this exploratory study, I determined in which inquiry phases the participants' were more likely to provide the most evidence of engagement and how these participants used the various sections of their PS online forums. I found that student-teams were more likely to provide evidence of quality engagement in the earlier phases on an inquiry cycle. These results were similar to findings in face-to-face inquiry settings. Scientist-mentors followed a similar trend with an emphasis in *Experimental Design and Procedures*. These findings suggest that both classroom teachers and scientist-mentors should explicitly address, scaffold, and motivate student-teams towards the completion of an inquiry cycle using tools such as the OEIC.

Participants used the various sections of their PS forums to interact and post materials. Participants communicated with each other directly via the *Discussion* thread. In addition to the *Discussion* section, the student-teams also posted materials and information in the other sections. Student-teams used the *Summary* section more frequently than the other sections of their forums. This section contains prompts that are designed to scaffold postings related to some parts of the inquiry cycle. Scaffolding by both scientist-mentors and programming appears to enable student-teams to provide greater evidence for engagement in the inquiry cycle. This evidence can be used by teachers, scientist-mentors, and the students themselves for formative and summative forms of assessment.

Chapter V describes the process and results of a study were I compared the inquiry cycle engagement of workshop and non-workshop teachers' student-teams. During this study, I determined the differences between the two types of student-teams in regard to their engagement in each element of inquiry. The two types of student-teams did not differ in the number of posts that they made, however, differences were found for their engagement in an inquiry cycle. These differences occurred throughout the cycle and were typically associated with the workshop teachers' experiences during their PD. These results suggest that the PS PD had a positive impact on student outcomes related to their engagement in an inquiry cycle.

Revision of the OEIC

In light of additional readings and recommendations, the *Conclusions and Explanations* section of the OEIC will be modified for future studies. Sandoval and Reiser (2003) emphasize that argumentation, which incorporates conclusions and justifications, should use evidence. Evidence represents the researcher's selection and interpretation of data that supports the researcher's arguments. The change of the wording on the OEIC items reflects the nuances between data and evidence along with their role in argumentation. (See Table 6.1.) As the researcher who evaluated the 263 student-teams using the OEIC, I examined the evidence provided by the student-teams when evaluating their conclusions and explanations. Thus the results of this dissertation can be compared to future studies.

In addition, another element — Did the learners demonstrate that they could select and/or identify appropriate evidence from their data? — can also be added to the Conclusions and Explanations section of the OEIC to further emphasize the difference between data and evidence. Furthermore this element would discern if the leaners can demonstrate that they recognize these differences and can apply this understanding to their own argumentation. Additional changes to the OEIC are also anticipated once the Next Generation Science Standards, which are currently under development, are released in 2013 (National Science Teachers Association, 2012).

Table 6.1
A list comparing the original and modified items from the Conclusions and Explanations section of the checklist

Original Item	Modified Item
Are the conclusions of the experiment connected to the data that was collected?	Are the conclusions of the experiment connected to the evidence that was collected?
Are the conclusions consistent with the data that was collected?	Are the conclusions consistent with the evidence that was collected?
Did the learners support ideas about causality with data?	Did the learners support ideas about causality with evidence?
Did the learners justify their conclusions using data?	Did the learners justify their conclusions using evidence?

Pattern Theory

I used pattern theory to make sense of my research findings, which allowed me to come to several conclusions. I recognize that these conclusions can change over time as new information is integrated. Student-teams and scientist-mentors, alike, typically focused on the beginning phases of an inquiry cycle. In addition to the beginning stages, student-teams also provided evidence of participation in *Analysis and Results*. Student-teams were also more likely to provide evidence of engagement for the heavily scaffolded sections of the forum that corresponded to an inquiry phase. Scientist-mentors, however, posted less often than student-teams with the exception of *Experimental Design and Procedures*. Both groups did not emphasize the first and final phases. (See Figure 6.1.) Exemplary student-teams followed a similar pattern of focus, only they provided more evidence of engagement. There was one deviation of note of this pattern, which was exemplary student-teams' extensive engagement in *Immersion*. (See Figure 6.2.) The evidence of engagement provide by all of the scientist-mentors was compared the evidence provided by the exemplary student-teams' scientist-mentors. Both groups showed similar patterns of engagement with the exemplary student-teams' scientist-mentors showing slight increases in the evidence provided for each inquiry phase engagement. (See Figure 6.3.) The sharp increase in the evidence provided for the *Immersion* phase found in the exemplary student-teams results did not appear. These patterns indicated that the presence evidence for the *Immersion* phase resulted from the student-team themselves and the face-to-face classroom environment. These trends also implicate *Immersion* as a key factor in successful inquiry implementations.

Student-team motivation might be also be another factor related to successful inquiry implementations. Student-teams appear to be more highly motivated at the start of the inquiry cycle, however, their motivation wanes as their cycle continues. Exemplary student-teams are potentially more motivated to complete the inquiry cycle which could account for the differences in the amount of evidence for engagement in an complete inquiry cycle. Student-team motivation, in part, could be related to engagement in immersion activities.

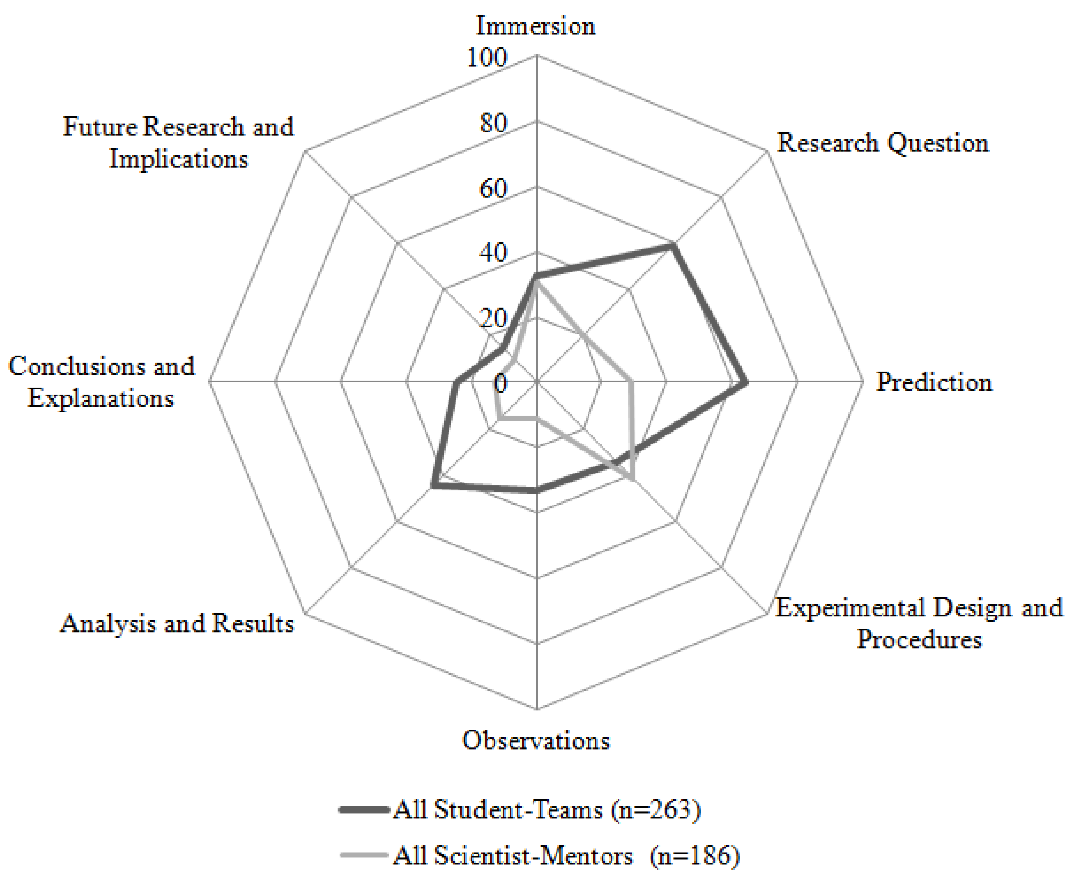


Figure 6.1. Percent of student-teams (n=263) and scientist-mentors (n=263) providing evidence of engagement within eight inquiry phases.

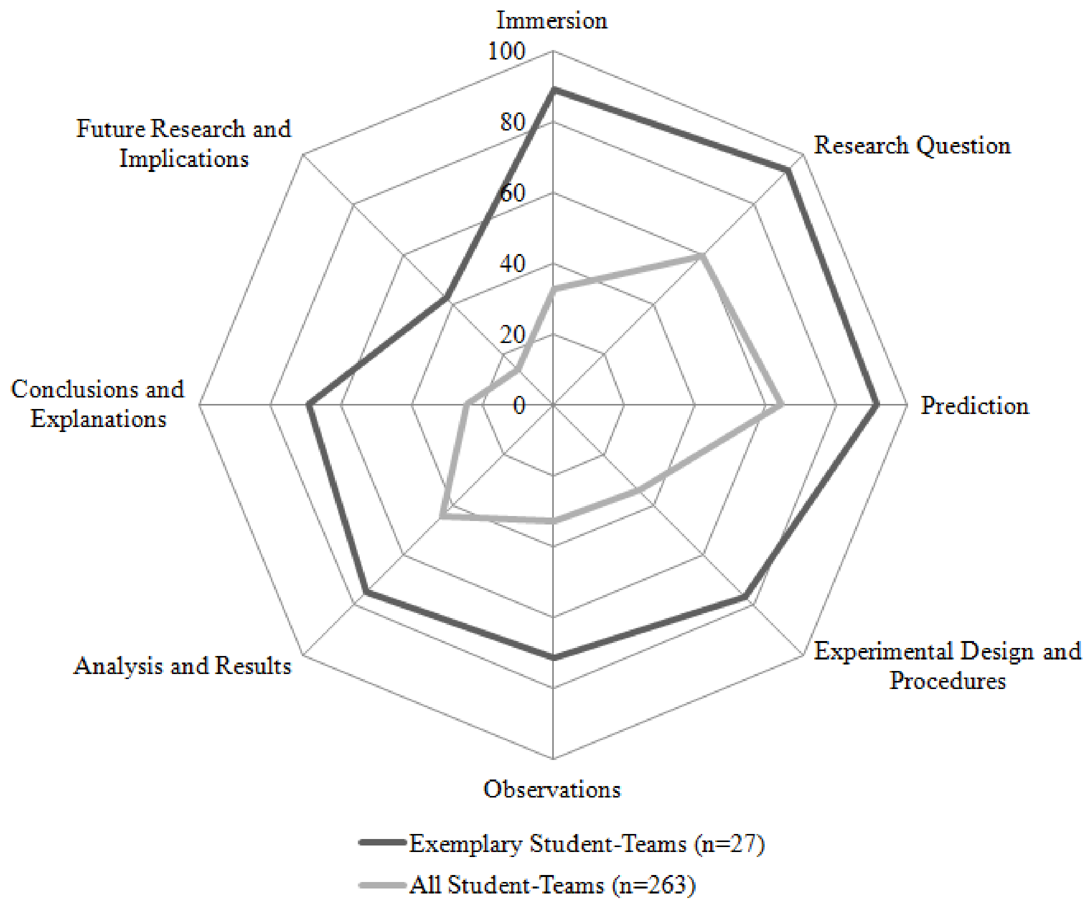


Figure 6.2. Percent of the top 10% percent of student-teams (n=27) and all of the student-teams (n=263) providing evidence of engagement within eight inquiry phases.

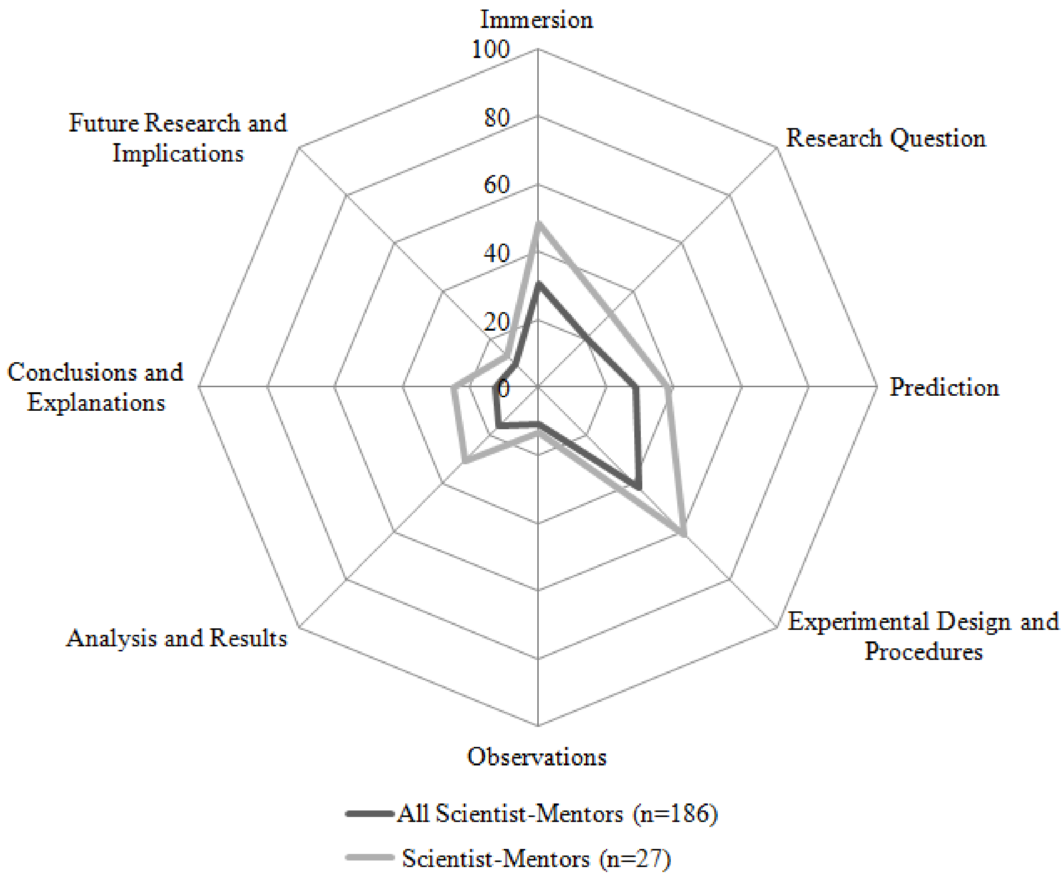


Figure 6.3. Percent of the top 10% of student-teams' scientist-mentors (n=27) and all of the student-teams' scientist-mentors (n=186) providing evidence of engagement within eight inquiry phases.

Since student-teams and their face-to-face classrooms appear to impact the positive and pronounced increase in student-teams' *Immersion* phase engagement, I examined the demographics of the 27 exemplary student-teams for further patterns. The workshop and non-workshop teachers' student-teams were represented in the same proportions as that of the entire sample along with the module type and grade level. However, 11 of the 27 student-teams attended private schools. Private school students' are not required to undergo state mandated testing and as a result teachers do not have to spend classroom time “teaching to the test.” Teachers in private school settings have less external time and subject matter constraints. This could result in student-teams who have more time to focus on and complete an inquiry project. Three of the 27 student-teams attended a public high school that specializes in project-based learning. Students at this school are familiar with being taught by reform-based methods and are allotted the time to engage reform-based learning. In addition, of the 16 different teachers represented in this sub-sample, seven of them attended schools where more than two teachers were represented in the sub-sample. Two more of those teachers attended schools where another teacher was present in the entire sample of 263 student-teams but were not present in the exemplary student-team sub-sample. These trends indicated that students are more likely to engage in a complete inquiry cycle if they attend a school where multiple teachers are committed to teaching PS and if the school is either private or a public school that is dedicated to reform-based teaching and learning.

Overall, workshop and non-workshop teachers’ student-teams were proportionally represented in the exemplary student sub-sample. This patterns indicates that both groups of students engaged in the phases of inquiry equally well within the exemplary examples. The results of the last study (Chapter IV), however, indicated that differences exist for some of the inquiry elements. Typically, workshop teachers’ student-teams provided more evidence of engagement for certain elements of inquiry, especially in relation to *Experimental Design and Procedures*. Also, these differences between the two student groups occurred throughout the inquiry cycle with exception of

Analysis and Results and *Future Research and Implications*. With the exception of the difference found in *Prediction*, all of the differences between workshop and non-workshop teachers' student-teams could be attributed to the teachers' summer workshop PD experience.

Examination of the various patterns revealed differences in the *Immersion* phase. Workshop teachers' student-teams provided more evidence of engaging in immersion activities than non-workshop teachers' students. Furthermore, exemplary students were also more likely to provide evidence for *Immersion*. These findings implicate *Immersion* as a key phase for the successful completion of an inquiry cycle. *Future Research and Implications* also appears to have implications for the successful completion of an inquiry cycle. This phase was largely neglected by all of the student-teams, exemplary student-teams, and scientist-mentors. In addition, scaffolding for this particular phase is not provided within the student-teams' forums. Scaffolding, either through mentoring or the online platform itself, is needed for student-teams to complete an inquiry cycle.

Future Research

In this dissertation, after first developing a valid and reliable means of assessment, I provided baseline information for how participants engage in an inquiry cycle while using the PS online learning system and which parts of the PS forums were used. In addition, I also determined the associations between teacher workshop attendance and student inquiry outcomes. My dissertation research also resulted in a database useful for exploring research questions. This database is easily accessible and can be used to efficiently sift through the data. For example, the results of my application of pattern theory indicated that *Immersion* is a key inquiry phase. One of the future studies that I plan to conduct explores how PS participants, especially student-teams, engage in the *Immersion* phase. The database enables me to quickly determine which student-teams provided evidence of engagement in one or both of the elements of inquiry related to *Immersion*. I can then conduct both qualitative and quantitative analyses to explore *Immersion* engagement and its relationship to other phases of an inquiry cycle.

Aside from questions regarding *Immersion*, my research has opened possibilities of exploring the inquiry cycle in other ways. The database also enables researchers to identify how changes to the platform, mentoring, modules, student-team motivation, and workshop impact participant engagement in an inquiry cycle. In addition, researchers can apply the OEIC to participants' forums and explore the outcomes based on the various variables such as module type, grade level, mentoring experience, etc.

This database could also aid a researcher in exploring student-teams' deeper understanding of various scientific practices and proficiencies. For example, if I wanted to find evidence of how students know, use, and interpret scientific explanations of the natural world (NRC, 2007), I would first identify student-teams providing evidence for most or all of the elements found in the *Conclusions and Explanations* phase. Then I would examine how these student-teams apply their understanding of natural phenomena to address the evidence they generated from their inquiries. In addition, using the evidence provided online I can look at what thinking these students chose to make visible by their posts and examine how their thinking changed through the course of the investigation.

In addition to the online evidence of inquiry engagement, recordings of the summer workshop PD experiences also exist. These recordings could be used to examine how the various elements of inquiry were addressed during the workshop. For example, I found differences between the workshop and non-workshop student-teams in regard to their immersion experiences. Using the recordings, I could explore how the scientists immersed the workshop teachers in the inquiry module and provide recommendations for how to scaffold students and for further workshops.

Implications

The results of this dissertation have a myriad of implications. For the designers of online learning systems, this dissertation provides evidence for recommendations regarding the scaffolding of website forums. To fully support student engagement in an inquiry cycle, my findings indicate that the website should contain additional scaffolding. I found that student-teams provided more evidence for engagement in the parts of the forum specifically addressing a particular phase of an inquiry cycle. I also found that student-teams do not engage in *Immersion* and *Future Research and Implications* as often as the other phases. I suggest a modification to the *Summary* section of the forum to consist of an addition of two subsections corresponding to those two phases of the inquiry cycle. These sections could scaffold the students' completion of an inquiry cycle.

For teachers and scientist-mentors, this dissertation provides recommendations for scaffolding and assessing student engagement in an inquiry cycle. Evidence shows that not only are students are lacking engagement in a complete inquiry cycle, but scientist-mentors show a similar pattern and teachers rarely posted. The PS facilitators should inform their teachers and scientist-mentors of these findings. The OEIC and its guide can be used for assessment and scaffolding. The OEIC provides a list of elements that defines quality engagement components for each phase of an inquiry cycles. Scientist-mentors and teachers should reflect each element of inquiry in their discourse with their students and use the checklist as a way to both formatively and summatively asses their students.

For the students, these studies can provide recommendations for what they should include in their online postings. Students should be made aware of the various phases of inquiry and what constitutes full engagement in an inquiry cycle. Students should be aware that previous student-teams examples typically do not contain all of the evidence that is necessary to have engaged fully in inquiry. A modified form of the OEIC can be used to enable students to reflect on and revise their own investigations. Furthermore, student-teams should be provided with explicit examples of exemplary and incomplete evidence for engagement for each element of inquiry found in the OEIC. This would provide the student-teams with additional scaffolding which could help them determine what to post as online evidence for their inquiry cycle engagement and provide motivation for complete inquiry cycle engagement.

For funding agencies and professional development providers, PS provides evidence that a quality professional development environment can be associated with positive student outcomes. These student outcomes appear to be associated with the activities and discussions that occurred during the PD workshops for teachers focusing on both hands-on and online parts of the PS learning system. For example, the scientists' facilitated a prolonged period of immersion and the workshop teachers' students provided evidence that they had engaged in immersive activities. PS should continue to provide quality PD experiences that are intensive, prolonged, facilitated by scientists, and driven by reform-based teaching and learning. In addition, all phases of an inquiry cycle should be explicitly addressed during the workshop. Also over half of the exemplary student-teams attended a school where more than one teacher was participating in PD. PD is typically more effective when it part of the reform efforts of an entire school rather than in individual and isolated classrooms. PS should encourage the attendance of multiple teachers from the same school at their PD workshops, which will encourage teachers to not only form collaborative communities online but also within their own schools.

For science education researchers, this dissertation provides a reliable and valid research instrument useful in assessing and evaluating online inquiry-based engagement developing scientific practices and proficiencies. In addition, the baseline use and engagement of participants' in an inquiry has been established. The effect of changes to the PS innovative online system in regard to participants' engagement in an inquiry cycle and their use of the online forums can be determined in subsequent studies. This dissertation is also generative provides a starting point from which other research studies, especially qualitative, can be derived.

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Research Information

Research Question

How will fertilizer affect the growth of plants?

Research Predictions

The more fertilizer there is, the more it will increase the growth rate and the amount of growth in the seeds. There will be different amounts of growth wil the same amount of fertilizer according to the type of seed.

Experimental Design

Our expiremental design is that we will place 5 varieties of seeds in plastic bags. There will be 4 seeds of one kind per bag and 3 bags for one typed of seed, each will a piece of filter paper moistened with different amounts of liquid fertilizer and distilled water equaling 10 mL. We will place each of these under an equal amount of just normal classroom light. The constant variables are the amount of light, type of water, amount of time between each measurement recording, amount of filter paper, size of bag, type of liquid fertiizer(pretty sure it was Miracle Gro), number of seeds in each bag(except fot the two bags we missed), and and temperature of the environment. We will measure the plants by observing and measuring the speed of growth through recording when and by how much the seeds beggining roots grow. We will place our data in a chart day by day. At the end of the experiement, we will place all our data in a growth graph and compare results.

Research Conclusions

Our conclusion did not support our hypothesis. The seeds with only fertilizer and half fertilizer did not grow at all. The seeds with all water grew very well. We obseved that seeds do not need fertilizer to germinate, they already have a supply of nutrients in them. Too many nutients hinder
the growth of the seeds.

Conversations - use this space to communicate about this project

Only logged in users are allowed to comment. register/log in

March 30, 2009 | 4:50 AM | Dr. Lena Struwe **(Scientist/Mentor)**

Thank you for all your efforts!

Your graphs look great, and I really liked your experiment. Of course you would do it differently in the future, but that is part of doing experiments. You finetune them as you go along, and learn from your results. You have been a great team! If I was your teacher I would definitely give you an A+ on your project, and your efforts has really shown that you have been thinking about this and you did great work in presenting your results, data, and experimental design. Good luck in all future things!

March 30, 2009 | 12:42 AM | PS team

Good bye

Thank you everyone who participated in this inquiry!

We hope you are going away with some new insights about how science works, and confidence that you can take on new scientific challenges. There are a lot of fascinating research questions---just waiting for young investigators to join in the fun.

Research Team Profile

Vine Swingers

Project Data

Our Uploaded Journals:

- ExperimentalDesignMatrix.doc.docx (11.61k)
- BiologyGerminationHW1.doc.docx (14.74k)

Our Uploaded Data Files:

- ExcellayoutforPlantLab1-Biology.xls (39.00k)

Our Uploaded Final Presentation Files:

- Seedgrowthcharts.docx (858.08k)

Images:

APPENDIX B

ONLINE ELEMENTS OF INQUIRY CHECKLIST

Team Code________________________________

Summary Table	Online Evidence								
	Discussant				Source				
	Student	Scientist	Teacher	Other Student	Discussion	Journal	Data	Summary	Additional
Which of the following were included in the electronic records for this team's inquiry project?									
	Total number of posts for each type of discussant				Check box if record is present				

Immersion or Setting the Stage	Online Evidence								
	Discussant				Source				
	Student	Scientist	Teacher	Other Student	Discussion	Journal	Data	Summary	Additional
Is there mention of **information-gathering efforts** (e.g., prior knowledge and/or experiences such as hands-on immersion activities, video- or audio-recordings, demonstrations, readings, discussion with scientists) that occurred before students posed their research question?									
Is there mention of prior knowledge or experiences that enabled the learners to question the **relationships between variables**?									

Research Question	Online Evidence								
	Discussant				Source				
	Student	Scientist	Teacher	Other Student	Discussion	Journal	Data	Summary	Additional
Is the research question appropriate for the context of the study?									
Are variables of interest observable and/or measurable?									
Is there explicit evidence that the research question is tied to prior knowledge or experience?									
Is there evidence that students chose their own research questions?									
Can the research question be answered within the scope and boundaries of the inquiry setting?									
Is the research question logically linked to a prediction, hypothesis, or expectation?									
If the question is causal in nature, is the research question **testable** through a scientific investigation?									
If the question is causal, is a relationship between the variables the focus of the research question?									

Prediction	Online Evidence								
	Discussant				Source				
	Student	Scientist	Teacher	Other Student	Discussion	Journal	Data	Summary	Additional
Is there evidence that the learners have considered possible or probable outcomes to their investigation?									
Is there evidence that a projected outcome (i.e., prediction, hypothesis, or expectation) is based on prior knowledge or experience?									
Is the predicted outcome reasonable in light of the research question that is being asked?									

Experimental Design and Procedures	Online Evidence								
	Discussant				Source				
	Student	Scientist	Teacher	Other Student	Discussion	Journal	Data	Summary	Additional
Did the research design enable the learners to answer their research question?									
Is there evidence that students themselves **developed** research methods?									
Is there a description of research methods in enough detail so that another research group could replicate them?									
Did the learners mention confounding variables?									
Are controls of variables mentioned?									
Is there mention that the learners controlled for possible sources of error in their observation methods?									

Observations	Online Evidence								
	Discussant				Source				
	Student	Scientist	Teacher	Other Student	Discussion	Journal	Data	Summary	Additional
Is there evidence that research events were recorded?									
Did the learners describe what they observed?									
Are data tables included in the inquiry project?									
Did the learners describe or discuss the data table(s)?									
Did the learners provide visual displays of their data such as graphs, charts, or pictures?									
Did the learners describe or discuss the visual displays?									
Do the visual displays follow accepted conventions (labels, legends, units of measure, accurate format)?									

Analysis and Results	Online Evidence								
	Discussant				Source				
	Student	Scientist	Teacher	Other Student	Discussion	Journal	Data	Summary	Additional
Did the learners mention patterns or trends in the data?									
Did the learners compare data across multiple studies from other student groups?									
Did the learners mention unexpected results?									
Was the data used to answer the research question?									

Conclusions and Explanations	Online Evidence								
	Discussant				Source				
	Student	Scientist	Teacher	Other Student	Discussion	Journal	Data	Summary	Additional
Are the conclusions of the experiment connected to the data that was collected?									
Are the conclusions consistent with the data that was collected?									
Did the learners support ideas about causality with data?									
Is there mention of alternative explanations?									
Did the learners compare their results to other studies' results?									
Did the learners discuss the limitations of their research?									
Did the learners justify their conclusions using data?									
Is there evidence of an expressed model or knowledge claim that explains relationships among variables with the natural phenomenon under investigation?									

Future Research and Implications of the Study	Online Evidence								
	Discussant				Source				
	Student	Scientist	Teacher	Other Student	Discussion	Journal	Data	Summary	Additional
Did the learners discuss the implications of their study?									
Is there mention of possible study revisions?									

APPENDIX C

A GUIDE TO THE ONLINE ELEMENTS OF INQUIRY CHECKLIST

Using the Elements of Inquiry Checklist

Purpose

This checklist has two purposes: (1) identify the parts of an inquiry cycle that are being discussed or posted during the online communication between students, scientists, and teachers; and (2) determine which parts of the *PlantingScience* platform are being used during the inquiry discussion. The checklist cannot be used to document the classroom-based face-to-face portion of the platform use.

How to use the checklist

Team Code

- ✓ This refers to the student team's code. For our example, the code is SSS_F07_011. It is used to identify the student team.

Discussants:

- ✓ *Student* refers to the student team and are labeled as Team Member. In your attached example this is the "Team Plant-A-Lot.". There are four members of the team; Dani, Andrew, Caitlin, and Michael. The four members of the team are considered one unit and are treated as a single entity.
- ✓ *Scientist* refers to the scientist/mentor.
- ✓ *Teacher* refers to the students' teacher.
- ✓ *Other student* refers to any other student who enters the conversation. The additional student will appear as (Student, team name and code). Multiple students can enter into discussion and they are treated as a single unit.
- ✓ Occasionally other people may enter the conversation at the beginning or end. Please do not use their posts if they are used to welcome or say goodbye to the students.

Source: Please see attached example.

- ✓ *Discussion* refers to the posts that are made in the comment section.
- ✓ *Journal* refers to all files uploaded under the Uploaded Journals section. Individual students might post their own journal entries but for purposes of this checklist treat the journals as a single unit.

- ✓ *Data* refers to all files uploaded under Our Uploaded Data Files. Again treat multiple entries as a single unit.
- ✓ *Summary* refers to the information that is posted in the subcategories (Research Question, Research Prediction, Experimental Design, and Research Conclusions) under Research information.
- ✓ *Additional* refers to any information that is not included in the above categories. In your example additional sources include files posted under Uploaded Final Presentation Files and Images.

Evidence can be found in multiple locations. If evidence is present, in anyone of these sources, place a check in the box. Multiple boxes per category can be checked. For example, if a student team and a scientist mentor were discussing future research plans and the student team posted their research plans in their journal, the following boxes would be checked: student, scientist, discussion, and journal.

***This document contains definitions, explanations and examples for each of the categories found in the checklist. The evidence for each category can differ based on the type of discussant. If one of the other types of discussants (scientist mentor, teacher, and another student) provided hints, explanations, or examples for a particular category then the discussant will receive a checkmark though the students did not make the recommended changes or respond.

Strategies for Using the Checklist

- ✓ <u>Read everything first.</u> This checklist was designed to capture the essence of the entire inquiry experience that is shared online. For example, the first research question that the students asked may be inappropriate. However, if it were changed over time to one that was appropriate, the students would receive a checkmark on the checklist for that category (see page three for an explanation of an appropriate research question).
- ✓ Look for evidence in multiple locations.
- ✓ Do not try to use all the parts of the checklist at once. Break it down. Focus on either the students or the scientist mentor first, then go back and look for evidence from the perspective of the other discussant.
- ✓ Once the checklist is completed review all of the documents and discussion posts again. It is easy to miss evidence the first few times you read the material.

Explanations and Examples for Each Category of the Elements of Inquiry Checklist

Immersion or Setting the Stage

- ✓ Is there mention of **information-gathering efforts** (e.g., prior knowledge and/or experiences such as hands-on immersion activities, video- or audio-recordings, demonstrations, readings, discussion with scientists) that occurred before students posed their research question?
  - Example: "Germination refers to the process that occurs in plants where a planted seed embryo begins to grow and produce a seedling. This occurs under certain growing conditions which can be manipulated to test a certain factor like the amount of oxygen, existence of water, and temperature. " (WSHS_S09_W46)
- ✓ Is there mention of prior knowledge or experiences or prior knowledge that enabled the learners to question the **relationships between variables**?
  - Learners discuss experiences such as prior laboratory experiments, fieldwork, readings, popular media, immersion phase of this inquiry experience, and class discussion. These enable students to question the relationship between their selected variables. For example, do these learners discuss previous experiences that would enable them to explore the relationship between different types of light and photosynthesis?
  - Example: "What kind of light is best for photosynthesis in plants: fluorescent, incandescent, or natural sunlight? Our hypothesis was that natural sunlight would work the best; after all, the oldest land plant was around 425 million years ago, so why shouldn't sunlight be the best?" (SAE_S09_P21)

Research Question

- ✓ Is the research question appropriate for the context of the study?
  - Is the research question appropriate for what the students are exploring? If they would like to know what is happening, does their research question allow for a descriptive study? If they would like to know what is happening or how it is happening, does their research question examine processes and mechanisms? If they would like to study a causal effect, does their research question imply a relationship between variables?

- Example of a casual study: “Does hydroponics help corn seeds to grow taller, faster, and be more healthy-looking than normal potting soil and growing techniques?” (CNTH_F08_W04)

✓ Are variables of interest observable and/or measurable?

- Can the variables be measured or observed either qualitatively or quantitatively? For example, when determining the impact of different types of light on photosynthesis, the rate of photosynthesis can be measured through the use of an Oxygen Gas Sensor Chamber (there are multiple methods) and there are published values for the wavelength of the different light sources which could be used.

✓ Is there explicit evidence that the research question is tied to prior knowledge or experience?

- Is there evidence that the learners discussed previous studies that they conducted or read about? Did the learners use existing information to inform their research question?
- Example: The following selection was taken from background information “…Hydroponics also completely eliminates the danger of most pests. Unfortunately, it is a bit more difficult to do than regular plant-growing. Done correctly though, it can supposedly produce better plants.” The students’ research question was, “Does hydroponics help corn seeds to grow taller, faster, and be more healthy-looking than normal potting soil and growing techniques?” (CNTH_F08_W04)

✓ Is there evidence that the students chose their own research question?

- Who selected the research question; the students or the teacher? If it appears that the teacher selected the research question do not check it off.

✓ Can the research question be answered within the scope and boundaries of the inquiry setting?

- Is it possible to address the research question within the bounds of the inquiry setting? Some research questions are very broad or have too many confounding variables.

✓ Is the research question logically linked to a prediction, hypothesis, or expectation?

- Example: The students’ research question was, “Does hydroponics help corn seeds to grow taller, faster, and be more healthy-looking than normal potting soil and growing techniques?” They stated that, “Our prediction is that the plant treated by hydroponics will grow taller and more healthy looking (greener, and with more chlorophyll) and will possibly be the first to sprout and germinate faster than the others." (CNTH_F08_W04)

- ✓ If the question is causal in nature, is the research question **testable** through a scientific investigation?
  - Can this question be described, explained, or predicted through scientific investigations? Is the question grounded in scientific ideas and concepts? (NRC, 1996)
  - Example: "How will the rate of photosynthesis change in relation to different types of white (or nearly white) light?" (SAE_S09_P21)
- ✓ If the question is causal, is a relationship between the variables the focus of the research question?
  - Does this question explore the relationship between the variables? In the above research question example, the learners made this relationship explicit because they asked how the rate would change based on the type of light.

Prediction

- ✓ Is there evidence that the learners have considered possible or probable outcomes to their investigation?
  - Example: "Our prediction is that the plant treated by hydroponics will grow taller and more healthy looking (greener, and with more chlorophyll) and will be possible be the first to sprout and germinate faster than the others." (CNTH_F08_W04)
- ✓ Is there evidence that a projected outcome (i.e., prediction, hypothesis, or expectation) is based on prior knowledge or experience?
  - Example: "Based on other results I have seen I would think that hydroponics would work better because of the drainage holes poked into the bottom of the cup so that the roots can soak in the water and take some (nutrients) when needed." (CNTH_F08_W04)
- ✓ Is the predicted outcome reasonable in light of the research question that is being asked?

- In the example above the students based their prediction on prior knowledge. This led them to believe that hydroponics would be the best plant-growing option because of easy access to nutrients.

Experimental Design and Procedures

- ✓ Did the research design enable the learners to answer their research question?
  - Were students able to design a study that allowed them to collect appropriate data and answer their research questions? Did scientist mentors provide suggestions and comments designed to aid the students in the design process?
- ✓ Is there evidence that students themselves **developed** research methods?
  - Did the students develop their own research methods or were they given to them by their teacher? The methodology can be developed over time and through discussion not only in the class but online with scientist mentors, other students, and teachers.
- ✓ Is there a description of research methods in enough detail so that another research group could replicate them?
  - Did the learners describe an observation plan in enough detail that other learners could repeat the observations in their own classroom or laboratory?
  - Did the scientist mentor, teacher, or other students ask questions about or provide feedback regarding the description of research methods?
- ✓ Did the learners mention confounding variables?
  - There is evidence of knowledge of confounding variables. A confounding variable is one that may interfere with the findings. It is not a variable that is intentionally manipulated.
  - Example: The following is an example of a research question where students did not consider confounding variables. "Does monster energy effect seed germination?" (ECH_F08_W05) There are different ingredients in an energy drink that could potentially impact growth but they not are not considered nor are they controlled for.
- ✓ Are controls of variables mentioned?
  - Variables are isolated so competing hypotheses or research questions can be ruled out.

- Example: "Controlled Factors (List at least 5): The amount of light, type of water, amount of time between each measurement recording, amount of filter paper, size of bag, type of liquid fertilizer (pretty sure it was Miracle Grow), number of seeds in each bag (except for the two bags we missed), and temperature of the environment." (WSHS_S09_W46)

✓ Is there mention that the learners controlled for possible sources of error in their observation methods?

- Many sources of error during observations can be due to the observer. There are tools and techniques designed to help remove some of this user error. Simple examples include a single individual repeating measurements or having several people take the same measurement. A more complex example is the use of a device that can measure photon flux to determine the amount of light that a plant is receiving.
- Sources of error can also be due to error caused by observation instruments. Did the learners implement ways of decreasing their possible sources of error during the study?
- Example: "As for the stem measurements. I say that more measuring cannot be bad - the more ways in which you explore your data, the better at this point." (SCH_S09_W06)

Observations

✓ Is there evidence that research events were recorded?

- Did the students record what they observed during each observation period or did the scientist mentor ask the students about what they observed during each observation period? Did any of the discussants comment on the research events?

✓ Did the learners describe what they observed?

- In addition to listing the measurements or other observations that were taken, did the learners discuss these observations?
- Example: "After looking at the sunlight for about three minutes, we saw that the percent of oxygen rose from 18.2% to almost 19.1% in the sealed contained where we were measuring the oxygen. This showed a good raise in oxygen compared to those of the other two lights." (SAE_S09_P21)

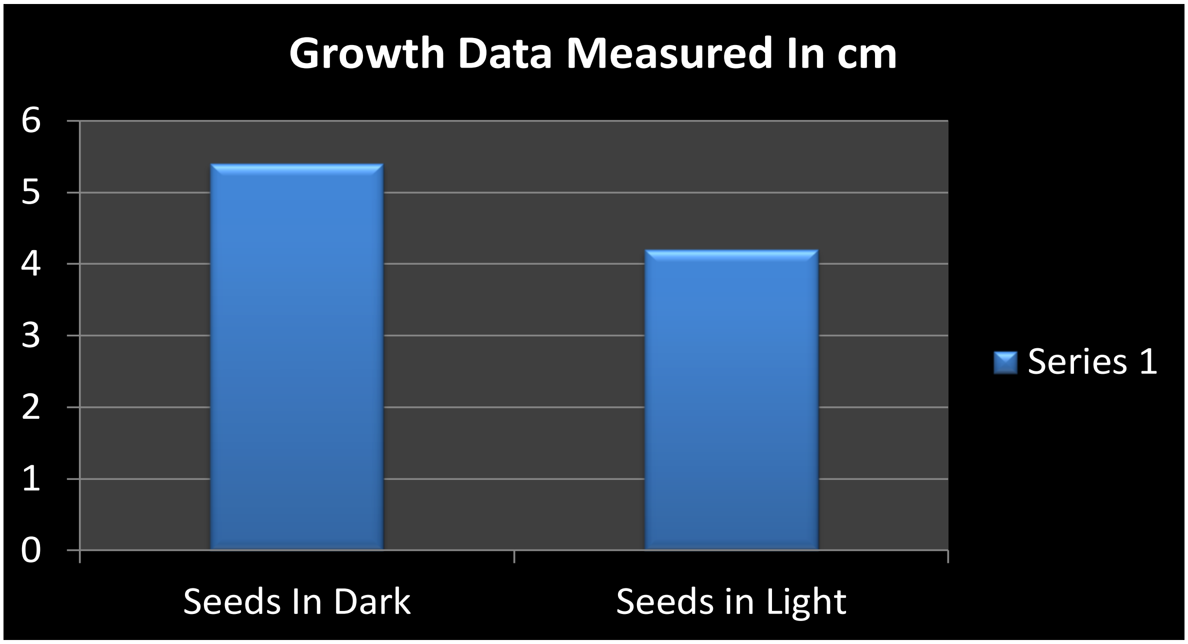
- ✓ Are data tables included in the inquiry project?
    - o Did the students upload or type in a data table? Did one of the other discussants, such as the scientist mentor, inquire about the inclusion of a data table?

Trial Number	Starting Point	Ending Point	Oxygen Used
Hairy Stem Trial A1	1.5 ml	0.4 ml	1.1 ml
Hairy Stem Trial A2	1.7 ml	0.65 ml	0.05 ml
Hairy Stem Trial B1	1.8 ml	1.1 ml	1.7 ml
Hairy Stem Trial B2	1.8 ml	1.5 ml	0.3 ml
Smooth Stem Trial A1	1.5 ml	0.4 ml	1.1 ml
Smooth Stem Trial A2	0.15 ml	0 ml	0.15 ml

(YSH_F08_R07)

- ✓ Did the learners describe or discuss the data table(s)?
    - o If the students created a data table, did they discuss or describe the information that was recorded in it? Did one of the discussants attempt to engage the student in a discussion about the data table?

- ✓ Did the learners provide visual displays of their data such as graphs, charts, or pictures?
    - o Did the students post any visual displays of their data? Did the other discussants ask about the inclusion of a visual display?



(YSH_F08_W11)

- ✓ Did the learners describe or discuss the visual displays?

  - If the students created a visual display did they discuss or describe the information that was recorded in it? Did one of the other discussants attempt to engage the students in a discussion about the data table?

  - Example: "In the experiment comparing the seeds grown with light to the seeds grown without light, the bar graph of our data shows that the seeds grown without light grew 1.2 cm taller than the seeds grown with light." (YSH_F08_W11)

- ✓ Do the visual displays follow accepted conventions (labels, legends, units of measure, accurate format)?

  - Are labels, legends, and units of measure present and correct? Is the format of visual display accurate? Did the scientist mentor or other discussant ask questions or provide feedback about accuracy of these visual displays?

Analysis and Results

- ✓ Did the learners mention patterns or trends in the data?
  - Did the learners discuss trends or patterns in the data?
  - Example: "In my temperature measurements I'm finding a pattern that the plant on the floor is always the coldest, the middle plant is most closest to the room temp., and the highest plant is colder than the middle plant but warmer than the floor plant." (SCH_S09_W06)
- ✓ Did the learners compare data across multiple studies from other student groups?
  - Did the learners use the *PlantingScience* website to find out if other students had conducted similar experiments? Did they reference other studies on the website? Did students from different classrooms post that they had done something similar and what their results were? Did the scientist or teachers refer them to other students' studies?
- ✓ Did the learners mention unexpected results?
  - Do anomalies appearing to be outliers (i.e., in graphs, charts, or recorded observations) appear to match expectations? If not, are the anomalies mentioned?
  - Example: "Also, it seems like some of the plants are shrinking because some of our data of the length of some of the plant roots from 2 days ago was different, as in greater lengths." (WSHS_S09_W46)
- ✓ Was the data used to answer the research question?
  - Did the students use data that enabled them to answer their research question? Did the other discussants ask questions that would prompt the students to use the data to answer their own questions?

Conclusions and Explanations

- ✓ Are the conclusions of the experiment connected to the data that was collected?
  - Are the conclusions directly related to the data collected?
  - Example: "We ended up with the highest of the 5 vermiculite plants growing to a remarkable 18 cm tall, towering above the other cups, with a vibrant green color and military stiffness, while the highest of the regular soil and hydroponics both reaching only 14 cm tall, the regular soil with a

slightly dark green color and about as much stiffness as the vermiculite, while the hydroponics plant was green-yellow with about as much stiffness as a wet sock…Going on this experiment, hydroponics definitely does not produce, greener, stiffer, and taller plants.” (CNTH_F08_W04)

- ✓ Are the conclusions consistent with the data that was collected?
  - In the above example, students concluded that the hydroponic plants did not grow as well as plants grown in other substrates. This conclusion was consistent with the data they collected.
- ✓ Did the learners support ideas about causality with data?
  - Did the learners use the data they collected to explain the causal relationships that they might be observing? In the following example, the students could have supported their conclusions further by referring back to their data set.
  - Example: “The seeds with only fertilizer and half fertilizer did not grow at all. The seeds with all water grew very well. We observed that seeds do not need fertilizer to germinate, they already have a supply of nutrients in them.” (WSHS_S09_W46)
- ✓ Is there mention of alternative explanations?
  - There might be another way of explaining the results of the study. Have the learners discussed these alternative explanations?
  - “Can the roots shrink or are we not measuring them correctly?” (WSHS_S09_W46)
- ✓ Did the learners compare their results to other studies’ results?
  - Did the learners indicate that they compared and contrasted other *PlantingScience* projects to their own? Did the study fit within the body of evidence that has already been collected?
  - Example: “There were no similar experiments on plantingscience.org so I couldn’t match any results.” (SCH_S09_W06)
- ✓ Did the learners discuss the limitations of their research?
  - Did the learners discuss limitations to their research such as the lack of time or replicates? Could they have measured something in a different way that would have led to more precise results?
- ✓ Did the learners justify their conclusions using data?

- When providing an explanation of the results of the study did the students refer back to their data set? Did the other discussants ask them questions about their results and relationship to the data or provide advice?

- Example: “In the experiment comparing the seeds grown with light to the seeds grown without light, the bar graph of our data shows that the seeds grown without light grew 1.2 cm taller than the seeds grown with light. Some qualitative data we have is that the seeds that were grown in light had darker seeds, the leaves were greener, and they stood more upright. The experiment proved that seeds don’t rely on light when sprouting (or when submerged under soil), but later in the germination process the seeds need the light. The seeds without the light sprouted faster but died at the end because of the lack of light. The seeds in the light sprouted slower but in the end were more lush green and looked healthier.” (YSH_F08_W11)

✓ Is there evidence of an expressed model or knowledge claim that explains relationships among variables with the natural phenomenon under investigation?

- Example: “The plants without light may have stretched themselves more than normal to try to reach a place with light. While the seeds that were already growing in light were growing at a normal place due to the light provided for them.” (YSH_F08_W11)

Future Research and Implications of the Study

✓ Did the learners discuss the implications of their study?

- The learners discuss the impact of their study. This could be how the results of study could be used to inform other studies or the application of what they have learned.

- Example: “The bigger picture of my experiment is that the best place to plant a flower is mid-altitude of a room. At this position the plant receives the most sunlight out of any of the other plants. The plants of the floor will most likely have a lot of dust and it can too easily be disturbed by other people in the room. The highest positioned plant won’t get enough sunlight and dust will also be an issue. A person who is going to plant a flower in a room is best off to plant it near a window on a counter that is about mid-level of the room.” (SCH_S09_W06)

✓ Is there mention of possible study revisions?

- Do the learners mention how the study could be changed? These changes might include the inclusion of replicates and changes to the research question, study design, or analysis.

- Example: “To redo this experiment, we would take more efficient data recordings, and use lesser percentages of the fertilizer.” (WSHS_09_W46

APPENDIX D

FREQUENCY TABLES

Table D-1
Percent of each type of participants providing quality evidences for each element of inquiry within ***Immersion or Setting the Stage***

Element of Inquiry	Student-Team n=263	Scientist-Mentor n=186	Teacher n=44	Other Student n=165
Is there mention of **information-gathering efforts** (e.g., prior knowledge and/or experiences such as hands-on immersion activities, video- or audio-recordings, demonstrations, readings, discussion with scientists) that occurred before students posed their research question?	34.6	32.7	2.3	0.8
Is there mention of prior knowledge or experiences that enabled the learners to question the **relationships between variables**?	30.4	28.1	1.9	0.8

Table D-2

Percent of each type of participants providing quality evidences for each element of inquiry within ***Research Questions***

Element of Inquiry	Student-Team n=263	Scientist-Mentor n=186	Teacher n=44	Other Student n=165
Is the research question appropriate for the context of the study?	85.9	36.1	2.3	1.1
Are variables of interest observable and/or measurable?	73.8	28.9	1.5	0.4
Is there explicit evidence that the research question is tied to prior knowledge or experience?	33.8	20.9	0.8	0.4
Is there evidence that students chose their own research questions?	51.3	24.3	1.1	0.8
Can the research question be answered within the scope and boundaries of the inquiry setting?	43.3	13.7	0.4	0.0
Is the research question logically linked to a prediction, hypothesis, or expectation?	58.9	12.5	0.4	0.4
If the question is causal in nature, is the research question **testable** through a scientific investigation?	63.9	14.1	0.4	0.4
If the question is causal, is a relationship between the variables the focus of the research question?	63.9	12.9	0.4	0.4

Table D-3

Percent of each type of participants providing quality evidences for each element of inquiry within ***Predictions***

Element of Inquiry	Student-Team n=263	Scientist-Mentor n=186	Teacher n=44	Other Student n=165
Is there evidence that the learners have considered possible or probable outcomes to their investigation?	92.8	38.8	1.1	3.4
Is there evidence that a projected outcome (i.e., prediction, hypothesis, or expectation) is based on prior knowledge or experience?	35.4	28.9	0.8	2.3
Is the predicted outcome reasonable in light of the research question that is being asked?	64.3	19.4	1.1	1.1

Table D-4

Percent of each type of participants providing quality evidences for each element of inquiry within ***Experimental Design and Procedures***

Element of Inquiry	Student-Team n=263	Scientist-Mentor n=186	Teacher n=44	Other Student n=165
Did the research design enable the learners to answer their research question?	62.0	70.3	3.4	4.9
Is there evidence that students themselves **developed** research methods?	42.2	29.7	1.1	1.1
Is there a description of research methods in enough detail so that another research group could replicate them?	28.9	52.1	3.0	4.6
Did the learners mention confounding variables?	21.7	39.2	1.5	1.1
Are controls of variables mentioned?	44.1	47.9	0.8	0.4
Is there mention that the learners controlled for possible sources of error in their observation methods?	6.8	11.8	1.5	0.0

Table D-5

Percent of each type of participants providing quality evidences for each element of inquiry within ***Observations***

Element of Inquiry	Student-Team n=263	Scientist-Mentor n=186	Teacher n=44	Other Student n=165
Is there evidence that research events were recorded?	72.2	26.6	4.9	0.0
Did the learners describe what they observed?	57.0	20.2	3.4	0.4
Are data tables included in the inquiry project?	29.7	6.5	0.8	0.0
Did the learners describe or discuss the data table(s)?	9.1	1.5	0.0	0.0
Did the learners provide visual displays of their data such as graphs, charts, or pictures?	35.4	15.6	1.1	0.8
Did the learners describe or discuss the visual displays?	9.1	3.0	0.0	0.0
Do the visual displays follow accepted conventions (labels, legends, units of measure, accurate format)?	17.9	3.4	0.0	0.0

Table D-6

Percent of each type of participants providing quality evidences for each element of inquiry within ***Analysis and Results***

Element of Inquiry	Student-Team n=263	Scientist-Mentor n=186	Teacher n=44	Other Student n=165
Did the learners mention patterns or trends in the data?	78.7	31.6	2.3	3.4
Did the learners compare data across multiple studies from other student groups?	1.5	1.5	0.0	1.1
Did the learners mention unexpected results?	47.9	20.9	0.0	1.1
Was the data used to answer the research question?	50.6	10.3	0.8	0.0

Table D-7
Percent of each type of participants providing quality evidences for each element of inquiry within ***Conclusions and Explanations***

Element of Inquiry	Student-Team n=263	Scientist-Mentor n=186	Teacher n=44	Other Student n=165
Are the conclusions of the experiment connected to the data that was collected?	52.1	20.5	3.0	0.8
Are the conclusions consistent with the data that was collected?	43.0	11.0	0.0	0.4
Did the learners support ideas about causality with data?	25.9	14.4	0.8	0.4
Is there mention of alternative explanations?	18.3	18.6	0.8	0.4
Did the learners compare their results to other studies' results?	2.7	1.5	0.0	0.8
Did the learners discuss the limitations of their research?	14.8	5.7	0.8	0.4
Did the learners justify their conclusions using data?	24.3	16.0	0.4	1.9
Is there evidence of an expressed model or knowledge claim that explains relationships among variables with the natural phenomenon under investigation?	13.7	13.3	2.7	1.1

Table D-8

Percent of each type of participants providing quality evidences for each element of inquiry within ***Future Research and Implications***

Element of Inquiry	Student-Team n=263	Scientist-Mentor n=186	Teacher n=44	Other Student n=165
Did the learners discuss the implications of their study?	5.7	5.3	0.0	1.1
Is there mention of possible study revisions?	22.8	14.1	3.4	0.8

Table D-9

Percent of platform use for each portion of the forum corresponding to the inquiry phase ***Immersion or Setting the Stage***

Element of Inquiry	Discussion (%)	Journal (%)	Data (%)	Summary (%)	Additional (%)
Is there mention of **information-gathering efforts** (e.g., prior knowledge and/or experiences such as hands-on immersion activities, video- or audio-recordings, demonstrations, readings, discussion with scientists) that occurred before students posed their research question?	39.9	17.9	0.0	4.2	6.1
Is there mention of prior knowledge or experiences that enabled the learners to question the **relationships between variables**?	36.5	14.1	0.0	4.2	6.1

Table D-10

Percent of platform use for each portion of the forum corresponding to the inquiry phase ***Research Questions***

Element of Inquiry	Discussion (%)	Journal (%)	Data (%)	Summary (%)	Additional (%)
Is the research question appropriate for the context of the study?	52.1	16.3	0.8	80.6	12.2
Are variables of interest observable and/or measurable?	43.7	16.0	0.8	66.2	11.8
Is there explicit evidence that the research question is tied to prior knowledge or experience?	29.7	14.4	0.0	5.7	6.8
Is there evidence that students chose their own research questions?	47.5	13.3	0.0	4.9	4.6
Can the research question be answered within the scope and boundaries of the inquiry setting?	21.3	10.3	0.0	31.6	8.7
Is the research question logically linked to a prediction, hypothesis, or expectation?	21.3	11.4	0.8	52.1	8.4
If the question is causal in nature, is the research question **testable** through a scientific investigation?	28.1	12.9	0.4	57.4	9.1
If the question is causal, is a relationship between the variables the focus of the research question?	26.6	12.9	0.4	57.8	8.7

Table D-11

Percent of platform use for each portion of the forum corresponding to the inquiry phase ***Predictions***

Element of Inquiry	Discussion (%)	Journal (%)	Data (%)	Summary (%)	Additional (%)
Is there evidence that the learners have considered possible or probable outcomes to their investigation?	49.4	16.7	1.1	86.7	9.9
Is there evidence that a projected outcome (i.e., prediction, hypothesis, or expectation) is based on prior knowledge or experience?	35.4	11.8	0.0	10.6	6.5
Is the predicted outcome reasonable in light of the research question that is being asked?	28.1	14.4	0.8	55.9	9.5

Table D-12

Percent of platform use for each portion of the forum corresponding to the inquiry phase ***Experimental Design and Procedures***

Element of Inquiry	Discussion (%)	Journal (%)	Data (%)	Summary (%)	Additional (%)
Did the research design enable the learners to answer their research question?	74.1	11.4	0.4	53.6	12.5
Is there evidence that students themselves **developed** research methods?	38.0	9.1	0.0	7.6	4.9
Is there a description of research methods in enough detail so that another research group could replicate them?	54.4	4.9	0.4	20.2	8.7
Did the learners mention confounding variables?	41.8	5.3	0.4	7.2	3.8
Are controls of variables mentioned?	51.3	7.2	1.1	23.2	8.0
Is there mention that the learners controlled for possible sources of error in their observation methods?	13.7	1.9	0.0	1.1	1.1

Table D-13

Percent of platform use for each portion of the forum corresponding to the inquiry phase ***Observations***

Element of Inquiry	Discussion (%)	Journal (%)	Data (%)	Summary (%)	Additional (%)
Is there evidence that research events were recorded?	46.8	34.2	22.8	12.5	14.1
Did the learners describe what they observed?	38.4	28.9	4.2	12.2	7.6
Are data tables included in the inquiry project?	7.6	4.2	22.8	1.1	4.2
Did the learners describe or discuss the data table(s)?	1.5	2.7	3.4	0.4	3.8
Did the learners provide visual displays of their data such as graphs, charts, or pictures?	17.1	2.3	18.3	0.4	17.9
Did the learners describe or discuss the visual displays?	3.0	2.3	0.0	0.8	6.1
Do the visual displays follow accepted conventions (labels, legends, units of measure, accurate format)?	3.8	1.1	11.0	0.0	7.2

Table D-14

Percent of platform use for each portion of the forum corresponding to the inquiry phase ***Analysis and Results***

Element of Inquiry	Discussion (%)	Journal (%)	Data (%)	Summary (%)	Additional (%)
Did the learners mention patterns or trends in the data?	57.4	26.2	1.1	48.3	11.8
Did the learners compare data across multiple studies from other student groups?	3.8	0.8	0.4	0.4	0.0
Did the learners mention unexpected results?	34.6	12.9	0.4	23.6	7.6
Was the data used to answer the research question?	25.5	11.8	0.4	32.7	9.9

Table D-15

Percent of platform use for each portion of the forum corresponding to the inquiry phase ***Conclusions and Explanations***

Element of Inquiry	Discussion (%)	Journal (%)	Data (%)	Summary (%)	Additional (%)
Are the conclusions of the experiment connected to the data that was collected?	33.5	10.3	0.8	35.4	11.8
Are the conclusions consistent with the data that was collected?	19.4	8.4	0.8	27.0	10.6
Did the learners support ideas about causality with data?	19.4	6.1	1.4	17.1	7.2
Is there mention of alternative explanations?	21.7	3.4	0.4	7.6	4.6
Did the learners compare their results to other studies' results?	2.3	0.4	0.4	1.1	0.4
Did the learners discuss the limitations of their research?	9.1	4.9	0.4	5.7	6.5
Did the learners justify their conclusions using data?	19.8	6.1	0.4	13.5	6.1
Is there evidence of an expressed model or knowledge claim that explains relationships among variables with the natural phenomenon under investigation?	16.7	1.9	0.0	7.2	1.9

Table D-16

Percent of platform use for each portion of the forum corresponding to the inquiry phase ***Future Research and Implications***

Element of Inquiry	Discussion (%)	Journal (%)	Data (%)	Summary (%)	Additional (%)
Did the learners discuss the implications of their study?	6.8	0.8	0.0	3.0	1.5
Is there mention of possible study revisions?	21.3	4.9	0.0	9.9	5.7

APPENDIX E

CHI-SQUARE TABLES

Table E-1
Chi-square test of independence for teacher workshop attendance and evidence of students' engagement in an element of inquiry for ***Immersion or Setting the Stage*** *(students whose teachers attended a workshop n=44; students whose teachers did not attend a workshop n=219)*

Element of Inquiry	Chi-square	*df*	*p*-level
Students mentioned of information-gathering efforts	5.537	1	0.019
Students mentioned prior knowledge or experiences that enabled them to question the relationships between variables.	0.882	1	0.348

Table E-2

Chi-square test of independence for teacher workshop attendance and evidence of students' engagement in an element of inquiry for **Research Question** *(students whose teachers attended a workshop n=44; students whose teachers did not attend a workshop n=219)*

Element of Inquiry	Chi-square	*df*	*p*-level
Students provided a research question that was appropriate for the context of the study.	0.320	1	0.572
Students discussed variables of interest that were observable and/or measurable.	0.913	1	0.339
Students provided explicit evidence that the research question is tied to prior knowledge or experience.	3.184	1	0.074
Students provided evidence that they chose their own research questions.	0.019	1	0.891
Students provided a research question that could be answered within the scope and boundaries of the inquiry setting.	6.985	1	0.008
Students logically linked their research question to a prediction, hypothesis, or expectation.	0.969	1	0.325
Students, if the question was causal in nature, provided a research question that was **testable** through a scientific investigation.	3.084	1	0.079
Students, if the question was causal in nature, provided a research question where the relationship between the variables was the focus.	4.411	1	0.036

Table E-3

Chi-square test of independence for teacher workshop attendance and evidence of students' engagement in an element of inquiry for **Predictions** *(students whose teachers attended a workshop n=44; students whose teachers did not attend a workshop n=219)*

Element of Inquiry	Chi-square	*df*	*p*-level
Students considered possible or probable outcomes to their investigation.	1.351	1	0.245
Students provided evidence that a projected outcome was based on prior knowledge or experience.	0.248	1	0.619
Students provided a predicted outcome that was reasonable in light of the research question that is being asked.	4.677	1	0.031

Table E-4

Chi-square test of independence for teacher workshop attendance and evidence of students' engagement in an element of inquiry for **Experimental Design and Procedures** *(students whose teachers attended a workshop n=44; students whose teachers did not attend a workshop n=219)*

Element of Inquiry	Chi-square	*df*	*p*-level
Students provided a research design that enabled them to answer their research question.	0.347	1	0.556
Students provided evidence that they developed research methods.	17.287	1	0.000
Students provided a description of research methods that was in enough detail so that another research group could replicate them.	1.434	1	0.231
Students mentioned confounding variables.	33.636	1	0.000
Students mentioned controls of variables.	0.281	1	0.596
Students controlled for possible sources of error in their observation methods.	1.693	1	0.193

Table E-5

Chi-square test of independence for teacher workshop attendance and evidence of students' engagement in an element of inquiry for **Observations** *(students whose teachers attended a workshop n=44; students whose teachers did not attend a workshop n=219)*

Element of Inquiry	Chi-square	*df*	*p*-level
Students recorded research events.	7.081	1	0.008
Students described what they observed.	5.310	1	0.021
Students included data table(s).	4.633	1	0.031
Students described or discussed the data table(s).	0.000	1	0.993
Students provided visual displays of their data such as graphs, charts, or pictures.	6.823	1	0.009
Students described or discussed the visual displays.	0.000	1	0.993
Students provided visual displays which follow accepted conventions (labels, legends, units of measure, accurate format).	4.398	1	0.036

Table E-6

Chi-square test of independence for teacher workshop attendance and evidence of students' engagement in an element of inquiry for **Analysis and Results** *(students whose teachers attended a workshop n=44; students whose teachers did not attend a workshop n=219)*

Element of Inquiry	Chi-square	*df*	*p*-level
Students mentioned patterns or trends in the data.	0.305	1	0.581
Students compared data across multiple studies from other student groups.	0.199	1	0.655
Students mentioned unexpected results.	0.403	1	0.525
Students used data to answer the research question.	0.825	1	0.364

Table E-7

Chi-square test of independence for teacher workshop attendance and evidence of students' engagement in an element of inquiry for **Conclusions and Explanations** *(students whose teachers attended a workshop n=44; students whose teachers did not attend a workshop n=219)*

Element of Inquiry	Chi-square	*df*	*p*-level
Students connected their conclusions of the experiment to the data that was collected.	9.016	1	0.003
Students had conclusions which were consistent with the data that was collected.	9.213	1	0.002
Students supported ideas about causality with data.	0.020	1	0.887
Students mentioned of alternative explanations.	0.710	1	0.400
Students compared their results to other studies' results.	0.724	1	0.395
Students discussed the limitations of their research.	1.324	1	0.250
Students justified their conclusions using data.	0.074	1	0.785
Students provided evidence of an expressed model or knowledge claim that explained relationships among variables with the natural phenomenon which was under investigation.	3.654	1	0.056

Table E-8

Chi-square test of independence for teacher workshop attendance and evidence of students' engagement in an element of inquiry for ***Future Research and Implications*** *(students whose teachers attended a workshop n=44; students whose teachers did not attend a workshop n=219)*

Element of Inquiry	Chi-square	*df*	*p*-level
Students discussed the implications of their study.	0.132	1	0.717
Students mentioned possible study revisions.	0.143	1	0.705

APPENDIX F

TEXAS A&M UNIVERSITY
DIVISION OF RESEARCH - OFFICE OF RESEARCH COMPLIANCE AND BIOSAFETY

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Human Subjects Protection Program — Institutional Review Board

APPROVAL DATE: 11-Apr-2012

MEMORANDUM

TO:	PETERSON, CHERYL ANN
FROM:	Office of Research Compliance Institutional Review Board
SUBJECT:	Initial Review

Protocol Number:	2012-0204
Title:	Mentored engagement of secondary science students, plant scientists, and teachers in an inquiry-based online learning environment
Review Category:	Exempt from IRB Review

It has been determined that the referenced protocol application meets the criteria for exemption and no further review is required. However, any amendment or modification to the protocol must be reported to the IRB and reviewed before being implemented to ensure the protocol still meets the criteria for exemption.

This determination was based on the following Code of Federal Regulations:
(http://www.hhs.gov/ohrp/humansubjects/guidance/45cfr46.htm)

45 CFR 46.101(b)(4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

Provisions:

Comments:

This electronic document provides notification of the review results by the Institutional Review Board.